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RESTRAINT SYSTEM DESIGN AND EVALUATION FOR MILITARY SPECIFIC APPLICATIONS

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RESTRAINT SYSTEM DESIGN AND EVALUATION FOR MILITARY SPECIFIC APPLICATIONS

By

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This dissertation has been approved in partial fulfillment of the requirements for the Degree of DOCTOR OF PHILOSOPHY in Mechanical Engineering - Engineering Mechanics.

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Preface

Within this dissertation projects are introduced, which were made possible by the collaboration of various Government Agencies and Contractors (Suppliers). The work in Chapter 2 was a joint collaboration with the U.S. Army Natick Soldier Systems Center, Pratt & Miller, IMMI and ASRC Federal (Formerly Primus Solutions). Dawn Woods from U.S. Army Natick collaborated on collecting the Soldier feedback, consolidating it and providing it to TARDEC for use in Restraint System Development. Pratt & Miller (Celyn Evans and Steve Reini), IMMI (Chris Jessup, Brandy Taylor, Kyle Paulson and Jacob White) and ASRC (Hans Steiniger and Molly O'Malley) provided data collection support. Various Soldiers participated in this study and provided feedback throughout the course of this project. Chapters 3 and 4 were made possibly by testing support at CAPE and restraint system engineering support from IMMI. Ryan Hoover from Cape, Chris Jessup and Kyle Paulson provided an overview, data and collaborated jointly to make the analysis happen. Chris Jessup, Kyle Paulson and Jacob White assisted in creating various restraint system designs and designing the impact surface, which was utilized in the sled testing series. Chris Jessup, Kyle Paulson and Jacob White redesigned the restraints and impact wall as needed all based on facts and data collected from the tests. Various Technicians helped setup, run the sled tests and provide the raw data. Testing was made possible by this entire team (CAPE and IMMI), without them the testing series and restraint system designs would not be possible. Craig Foster supported in the data collection and analysis throughout the program.

Acknowledgments

To my advisor committee at Michigan Technological University (Dr. Greg Odegard, Dr. Craig Friedrich, and Dr. Kelly Steelman) and TARDEC (Dr. John "Jack" Reed), thank you for mentoring and guiding me through this process. With the many hurdles that we encountered over the years, together we were able to navigate the waters and help me get to this point. Thank you for all that you have done to keep me on track.

To my dad who has pushed me since I was a little boy to always want to be the best in all that I do and never give up. To my wife whom I love very much, who was always there to encourage and support me through these difficult years. My family who encouraged me to be the best that I can be. I thank you and love you all!

To the TARDEC Ground Systems Survivability team, thank you for making this funding possible so that this research can push the limits of restraint system design and provide a framework for future military restraint development. With managements help (Risa Scherer) and support we were able to continue funding and continue developing and tweaking what restraints should be in a military vehicle.

Craig Foster dedicated his time to help mentor me and work closely with me on all of these projects. His ability to work under pressure is amazing, without him we could have not accomplished much of the testing, data analysis and data collection.

To each and every one of you I greatly appreciate all your help! Thank You!

List Of Abbreviations

APBI	Advanced Planning Briefing for Industry
ARL	Army Research Laboratory
ASME	American Society Of Mechanical Engineers
ATD	Anthropomorphic Test Device
BMT	Blast Mitigation Team
CAD	Computer Aided Design
CSBES	Crew Seating Blast Effects Simulator
DTIC	Defense Technical Information Center
EA	Energy Absorbing
ECE R	Economic Commission for Europe Regulation
EPS	Expanded Polystyrene
FMVSS	Federal Motor Vehicle Safety Standard
Fx	For-aft shear force
g's	Force of acceleration unit of measure
GSS	Ground System Survivability
GVSETS	Ground Vehicle Systems Engineering and Technology Symposium
IP	Instrument Panel
kHz	Kilohertz
mm	Millimeter
My	Moment
N	Newton
N-M	Newton Meter
NSRDEC	Natick Soldier Research, Development and Engineering Center
OCP	Occupant Centric Platform Technology Enabled Capability
TECD	Demonstrator
OEM	Original Equipment Manufacturer
PPE	Personal Protective Equipment
s	Seconds
SAE	Society Of Automotive Engineers
SAW	Squad Automatic Weapon
Sled	Moveable platform used in crashworthiness testing with an ATD
TARDEC	Tank Automotive Research Development And Engineering Center

Abstract

This research focuses on designing an optimal restraint system for usage in a military vehicle applications. The designed restraint system must accommodate a wide range of DHM's and ATD's with and without PPE such as: helmet, boots, and body armor. The evaluation of the restraint systems were conducted in a simulated vehicle environment, which was utilized to downselect the ideal restraint system for this program.

In December of 2011 the OCP TECD program was formulated to increase occupant protection. To do this, 3D computer models were created to accommodate the entire Soldier population in the Army. These models included the entire PPE, which were later utilized for space claim activities and for designing new seats and restraints, which would accommodate them. Additionally, guidelines to increase protection levels while providing optimal comfort to the Soldier were created. The current and emerging threats were evaluated and focused on at the time of the program inception.

Throughout this program various activities were conducted for restraint downselection including Soldier evaluations of various restraint system configurations. The Soldiers were given an opportunity to evaluate each system in a representative seat, which allowed them to position themselves in a manner consistent with the mission requirements. Systems ranged from fully automated to manual adjustment type systems. An evaluation of each particular system was conducted and analyzed against the other systems. It was discovered that the restraint systems, which utilize retractors allowed for automatic webbing stowage and allowed for easier access and repeatability when donning and doffing the restraint. It was also found that when an aid was introduced to help the Soldier don the restraint, it was more likely that such system would be utilized.

Restraints were evaluated in drop tower experiments in addition to actual blast tests. An evaluation with this amount of detail had not been attempted previously.

Chapter 1

Introduction

Historically, the assessment of restraint systems in the Department Of Defense (DOD) is typically dependent upon the programmatic requirements. There are no set type of specifications utilized by the Program Managers (PMs). Instead, Federal Motor Vehicle Safety Standards (FMVSS) 207, 209, and 210 are utilized to certify the restraint system and seat together as a system and are listed in Table 1.

Many seat contractors have stated that they have complied with FMVSS 208, a frontal crash standard utilized for the certification of all vehicles sold in the United States. However, this statement is incorrect for two reasons. First, the FMVSS 208 is intended for trucks and multipurpose passenger vehicles with a Ground Vehicle Weight Rating (GVWR) of 10,000 pounds or less [1]. Therefore, FMVSS is not applicable for military vehicles. Second, the only way to certify to FMVSS 208 properly would be to certify a vehicle in a crash test scenario as stated in Section 13 or Section 14 of FMVSS 208[i]. Instead, what the contractors will do is utilize the Section 13 body on sled crash pulse (also known as the generic pulse) intended for unbelted occupants. The seat is mounted rigidly onto a floor fixture and an ATD without PPE is tested. An ATD is device designed to be a surrogate in place for human testing. A 50^{th} percentile male ATD, with a SAW Gunner configuration encumbrance was utilized for the test series. The construction of the ATD consisted of accelerometers, potentiometers (neck and chest), and various load sensors. Injury metrics such as HIC, Chest Resultant, Chest Deflection, Neck FX (Force in the X direction), Neck MY (Moment in the Y Direction) and Pelvis Resultant were analyzed and a judgment of pass/fail was assigned. Loads from the chest potentiometer provide a better understanding of chest to PPE interaction. Restraint load cells capture loads imparted onto the restraints from the ATD that is analyzed to determine the severity of the crash or blast event.

Typically, with automotive restraint systems, the Original Equipment Manufacturer (OEM) will test the component level performance in addition to the system level performance of the system. This entails coupling the restraint system to a seat and surrounding environment to replicate the actual vehicle in a crash scenario best. To do this the OEM will run preliminary crash tests to generate an accelerative pulse, which is the acceleration or deceleration experienced during a crash event. Once this pulse is generated, it is no longer necessary to rerun crash tests to tune the safety system. Instead, the OEM will run a sled test; this test utilizes a reinforced body with seats, restraints, an IP, and as many parts as possible to replicate the interior environment of a vehicle. This sled carriage is then subjected to the crash accelerative pulse, thus replicating the initial crash test. This type of test is very repeatable and can be accomplished many times in a row. Once sled testing has been successful and the safety system is tuned, a final confirmation crash test is conducted accordingly and the vehicle is certified. With the advent of modeling and simulation, much of this testing can be conducted digitally to utilize correlated models before any real prototypes are built.

To better understand automotive crash certification in the United States one must consider all the applicable standards that exist. NHTSA (National Traffic Highway Safety Administration) has a set and defined system for certifying vehicles for crashworthiness, namely FMVSS Table 1[1] highlights every applicable test standard for both cars and busses, which are utilized for crash certification in the United States.

Given the standards listed in Table 1 and Table 2 a review of all the highlighted standards (207,208,209, and 210) were analyzed to determine if they apply to military vehicles and if they were within the scope of this development. Military vehicle weight references can be found in Table 3[2].

Table 1: FMVSS CRASHWORTHINESS SAFETY STANDARD[1]

Part 571 Federal Motor Vehicle Safety Standards CRASHWORTHINESS	
Standard No. 201	Occupant Protection in Interior Impact
Standard No. 202	Head Restraints
Standard No. 203	Impact Protection for the Driver from the Steering Control System
Standard No. 204	Steering Control Rearward Displacement
Standard No. 205	Glazing Materials
Standard No. 206	Door Locks and Door Retention Components
Standard No. 207	Seating Systems
Standard No. 208	Occupant Crash Protection
Standard No. 209	Seat Belt Assemblies
Standard No. 210	Seat Belt Assembly Anchorages
Standard No. 211	[Reserved]
Standard No. 212	Windshield Mounting
Standard No. 213	Child Restraint Systems
Standard No. 214	Side Impact Protection
Standard No. 216	Roof Crush Resistance
Standard No. 217	Bus Emergency Exits and Window Retention and Release
Standard No. 218	Motorcycle Helmets
Standard No. 219	Windshield Zone Intrusion
Standard No. 220	School Bus Rollover Protection
Standard No. 221	School Bus Body Joint Strength
Standard No. 222	School Bus Passenger Seating and Crash Protection
Standard No. 223	Rear Impact Guards
Standard No. 224	Rear Impact Protection

Table 2: FMVSS POST CRASH EVALUATION STANDARDS[1]

Part 571 Federal Motor Vehicle Safety Standards POST CRASH STANDARDS	
Standard No. 301	Fuel System Integrity
Standard No. 302	Flammability of Interior Materials
Standard No. 303	Fuel System Integrity of Compressed Natural Gas Vehicles
Standard No. 304	Compressed Natural Gas Fuel Container Integrity
Standard No. 500	Low Speed Vehicles

Table 3: General Military Vehicle Weights[2]

Wheeled Vehicles					Tracked Vehicles
High Speed, Agile, Light Vehicles	Wheeled Combat & Derivative Vehicles 6x6, 8x8	Medium Transport & Support Vehicles w/wo Trailers	Heavy Transport Vehicles w/wo Trailers	Tank Transporters	
WT 10,000 to 20,000 lbs	WT 20,000 to 60,000 lbs	WT 20,000 to 80,000 lbs	WT 80,000 to 140,000 lbs	Over 140,000 lbs	All
Axle Loads to 10,000 lbs	Axle Loads to 15,000 lbs	Axle Loads to 20,000 lbs	Axle Loads to 25,000 lbs	Axle Loads to 30,000 lbs	N/A
Max Speed 120 MPH	Max Speed 110 MPH	Max Speed 100 MPH	Max Speed 90 MPH	Max Speed 60 MPH	Max Speed 50 MPH
Examples:	Examples:	Examples:	Examples:	Examples:	Examples:
Replacement HMMWV	Improved Stryker	Family of Medium Tactical Vehicles (FMTV)	Uprated Palletized Load Systems	Uprated Tank Transporter	Bradley Fighting Vehicle
Military Derivatives of Private Sector Vehicles	Uprated FCS	Palletized Load System (PLS) w/o Trailer	M915/M916 Line Haul Trucks w/trailers	Heavy Equipment Transporters	Abrams Tank
Future High Agility Vehicles	Future Wheeled Combat and Direct Support Vehicles	Future Truck (Army)			

Since each of the vehicles in Table 3 are over 10,000 pounds, many FMVSS standards do not apply to them as shown in Table 4. It is important to note that FMVSS 301, 302, 303, 304, and 500 are out of scope for a restraint development program. FMVSS 211, 213, 217, 218, 220, 221, 222, 223, 224 do not apply to military vehicles since these standards apply to child restraints, bus, motorcycle, and semitrailers.

Table 4: FMVSS Application Chart

Part 571 Federal Motor Vehicle Safety Standards CRASHWORTHINESS				
		Is This Standard Vehicle Weight Dependent?	Does It Apply To Military Vehicles?	Is This Test Within Scope Of The Restraints Group Within The OCP TECD Program?
Standard No. 201	Occupant Protection in Interior Impact	Yes, Passenger Cars, Multipurpose Passenger Vehicles, Trucks with a Gross Vehicle Weight Rating of 4,536 kg (10,000 lbs.) or less, and Buses with a Gross Vehicle Weight Rating of 3,860 kg (8,510 lbs.) or less (Effective 9-1-2000)	No, Vehicles Exceed 10,000lbs	No
Standard No. 202	Head Restraints	Yes, Passenger Cars, Multipurpose Passenger Vehicles, Trucks and Buses with a Gross Vehicle Weight Rating of 4,536 kg (10,000 lbs.) or less (Effective 1-1-69)	No, Vehicles Exceed 10,000lbs	No
Standard No. 203	Impact Protection for the Driver from the Steering Control System	Yes, Passenger Cars (Effective 1-1-68), Multipurpose Passenger Vehicles, Trucks, and Buses with a Gross Vehicle Weight Rating of 4,536 kg (10,000 lbs.) or less (Effective 9-1-81)	No, Vehicles Exceed 10,000lbs	No
Standard No. 204	Steering Control Rearward Displacement	Yes, Passenger Cars (Effective 1-1-68), Multipurpose Passenger Vehicles, Trucks, and Buses with Unloaded Vehicle Weight (UVW) of 1,814 kg (4,000 lbs.) or less (Effective 9-1-81). UVW of 2,495 kg (5,500 lbs.) or less (Effective 9-1-91). Walk-in Vans are excluded.	No, Vehicles Exceed 5,500lbs	No
Standard No. 205	Glazing Materials	No, Passenger Cars, Multipurpose Passenger Vehicles, Trucks, Buses, Motorcycles, Slide-In Campers, and Pickup Covers [designed to carry persons while in motion] (Effective 1-1-68)	Yes	No
Standard No. 206	Door Locks and Door Retention Components	No, Passenger Cars (Effective 1-1-68), Multipurpose Passenger Vehicles (Effective 1-1-70), and Trucks (Effective 1-1-72)	Yes	No
Standard No. 207	Seating Systems	No, This standard applies to passenger cars, multipurpose passenger vehicles, trucks and buses.	Yes	Yes
Standard No. 208	Occupant Crash Protection	Yes, Trucks and multipurpose passenger vehicles with a GVWR of 10,000 pounds or less.	No, Vehicles Exceed 10,000lbs	No
Standard No. 209	Seat Belt Assemblies	No, This standard applies to passenger cars, multipurpose passenger vehicles, trucks and buses.	Yes	Yes
Standard No. 210	Seat Belt Assembly Anchorages	No, This standard applies to passenger cars, multipurpose passenger vehicles, trucks and buses.	Yes	Yes
Standard No. 212	Windshield Mounting	Yes, Trucks and multipurpose passenger vehicles with a GVWR of 10,000 pounds or less.	No, Vehicles Exceed 10,000lbs	No
Standard No. 214	Side Impact Protection	Yes, STATIC REQUIREMENT - Multipurpose Passenger Vehicles, Trucks and Buses with a Gross Vehicle Weight Rating of 4,536 kg (10,000 lbs.) or less (Effective 9-1-93) Shall meet phase-in schedule. (Effective 9-1-94) All shall meet requirements. CRASH TEST REQUIREMENT - Multipurpose Passenger Vehicles, Trucks and Buses with a Gross Vehicle Weight Rating of 2,722 kg (6,000 lbs.) or less (Effective 9-1-98) All shall meet requirements.	No, Vehicles Exceed Both 10,000lbs and 6,000lbs	No
Standard No. 216	Roof Crush Resistance	Yes, Passenger Cars (except convertibles) (Effective 9-1-75) and Multipurpose Passenger Vehicles, Trucks and Buses (except school buses) with a Gross Vehicle Weight Rating of 2722 kg (6,000 lbs.) or less (Effective 9-1-94)	No, Vehicles Exceed 6,000lbs	No
Standard No. 219	Windshield Zone Intrusion	Yes, Trucks and multipurpose passenger vehicles with a GVWR of 10,000 pounds or less.	No, Vehicles Exceed 10,000lbs	No

Understanding these requirements allows a military vehicle program to move forward with their system level design and evaluation. Since the vehicle weight exceeds 10,000 pounds actual crash testing would not be conducted for validation of the restraints system. The method of evaluation would instead consist of mounting a seat to a rigid floor plate on a sled as detailed in Figure 1 and Figure 2. Once the seat was available, a fixture would be made to accept the seat onto the sled and it is then ready to test. An ATD without PPE would then be seated onto the seat and have the restraints donned as shown in Figure 3. However, this evaluation would still not consider an actual vehicle pulse or consider utilizing PPE.

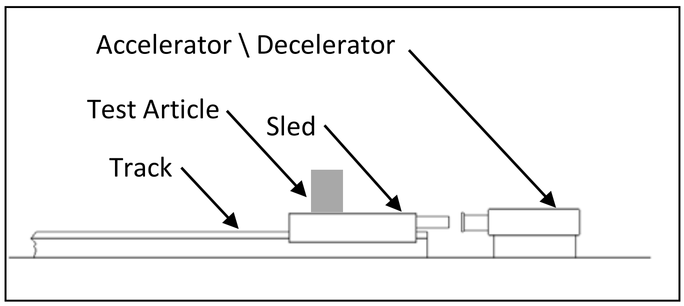

Figure 1: Crash Sled

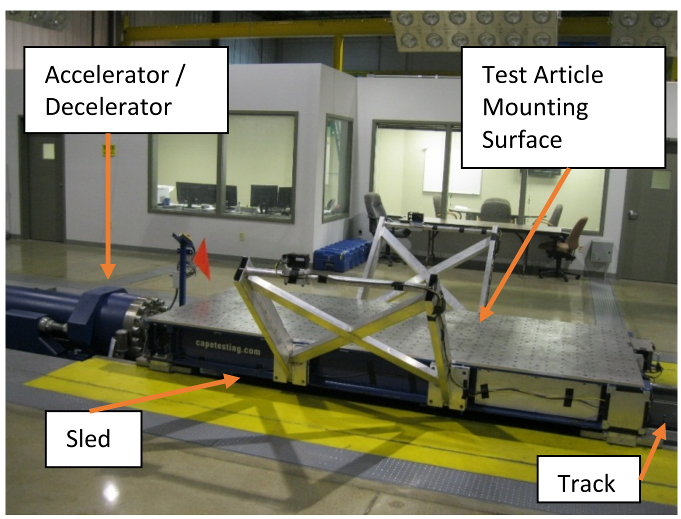

Figure 2: Servo-Hydraulic Sled

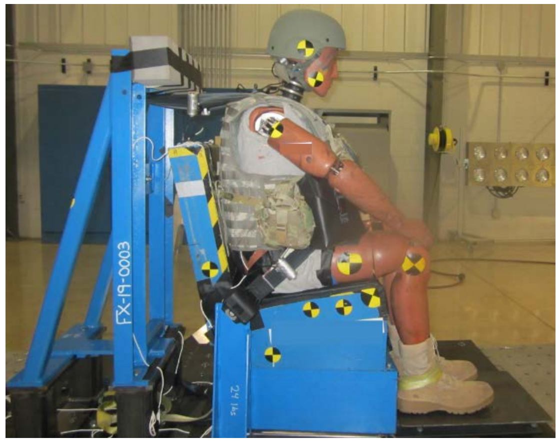

Figure 3: ATD On Sled

Prior to the OCP TECD program, PPE was not specifically defined for use on the ATD for testing at TARDEC. The PPE is critical as it adds weight and bulk to the ATD and effects the space claim around the seat. It is then not completely inconceivable that a 95th percentile ATD may have insufficient webbing available to don the restraints. In a real world scenario if the Soldier is not able to don the restraints, the potential for having the restraints removed from the vehicle increases.

It was with these and similar shortcomings in military vehicle design that an Army Science and Technology Advisory Group/Working Group (ASTAG/ASTWG) was created. The purpose was to align the Army's science and technology (S&T) program, to the Army's current and future capability challenges. The U.S. Army Research, Development and Engineering Command (RDECOM) was tasked with addressing these challenges and proposing the Technology Enabled Capability Demonstration (TECD) programs, which would then develop, integrate, and validate technologies that would provide the necessary capabilities identified in the challenge statements.

> The U.S. Army Tank Automotive Research, Development, and Engineering Center (TARDEC), Ground Systems Survivability (GSS) team was chosen to lead the Occupant Centric Platform (OCP) TECD and execute the following challenge statement
>
> "Formulate a S&T program to make improvements to existing platforms

or develop new platforms that provide appropriate increased protection from current and emerging threats and optimal space allocation for Soldiers and their gear, while decreasing platform weight and maintaining or increasing maneuverability during full spectrum operations."

To address this challenge, the OCP TECD developed, designed, demonstrated, and documented an occupant centered Army Ground Vehicle design philosophy that improved vehicle survivability as well as Soldier force protection by mitigating Soldier injury due to Under Body Improvised Explosive Device (UBIED) and under body mine blast, rollover, and crash events. OCP TECD provided increased force protection through the standardization of an "occupant-centric" or an "inside-out" approach to vehicle survivability system design, which included defining the optimized space required for the Soldier and their gear. In order to standardize this new approach, the program explored the possibility of adapting some of the automotive and racing industry's crash standards as military ground vehicle test standards. In addition, this program reviewed and redefined current military design standards and best practices for defining the space required to adequately fit the Soldier and his gear inside a ground vehicle, as well as create new standards and best practices, based on the program's occupant centric approach. This program also identified novel, off-the-shelf occupant protection technologies that were integrated onto a military platform in order to mitigate the effects of blast/crash event on an occupant[3].

Initially during the planning phases of OCP TECD, the team was to baseline a particular military vehicle model in various crash test modes to gather data such as vehicle crush, crash deceleration (crash pulse), and occupant crash performance. The goal was to replicate as many of the applicable FMVSS tests listed in Table 4.

With a defined crash pulse, the restraint system could be tuned to perform ideally in the various crash modes. This left the team with only sled testing to evaluate the restraint performance. This resulted in the creation of a simulated frontal crash pulse for the OCP TECD program. This pulse would be utilized throughout the entire program to validate the restraint system performance.

Restraint System Development and Evaluation

The restraint system development is broken down into chapters focusing on the following: restraint system evaluation, effects of encumbrance on restraint systems, proper restraint system routing procedures, the IP design and evaluation on encumbered Soldiers, and a conclusion.

Soldier Restraint System Evaluation

As the restraint system program was in its beginning stages, the OCP TECD team started interviewing Soldiers. The goal was to create a vehicle, which would not only protect the Soldiers but would also provide comfort. Many of the interviewed Soldiers had returned from theatre and provided details on various aspects of military vehicle operation and use. During these sessions, Soldiers were asked to evaluate various restraint system concepts and provide extensive feedback, which later guided a technology downselect. In addition to this, Soldiers were interviewed to determine what issues they experienced with restraints and what they would like to see integrated into the future design. With the restraint evaluation and suggestions, a conceptual restraint system could be designed and built for testing. A unique feature, which the Soldiers ranked highly, was the ReadyReach system. This system provides the restraints at optimal locations near the head and pelvis, which aid in donning them. The initial concept for military specific use was created at TARDEC with the assistance of the Advanced Concepts Team. This design was later provided to the contractor who then created prototypes for the Soldier evaluations as shown in Figure 4 and Figure 5.

Figure 4: Initial TARDEC Restraint Concept, Stowed Position

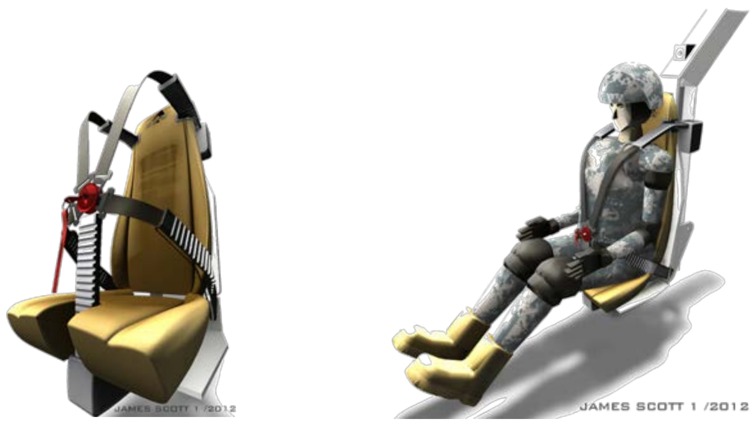

Figure 5: Initial TARDEC Restraint Concept, Donned Position

In its initial conceptual form, the 5th point of the restraint was to swing upwards toward the occupant once the seat foam was compressed. Due to complications in the design and the amount of space claim required for such an action, the feature was not integrated into the physical concepts. The physical concepts that included the ReadyReach feature were integrated onto generic seats, just as all of the other restraint systems were in the Soldier evaluation. Two variations of the ReadyReach restraint were evaluated. Both systems had the same shoulder and hip ReadyReach systems, which consisted of spring steel and a stop sewn in between the webbing. This caused the restraint to always return to the stowed position and remain erect. The difference between the two physical concepts came from the fifth point, which varied in design one from another. One system utilized spring steel sewn between two pieces of webbing; the buckle would be folded forward of the seat when stowed and then easily popped upwards (reaction of the spring steel) when ready for use. Figure 6 highlights the ReadyReach with the spring steel 5th point variant in the donned position.

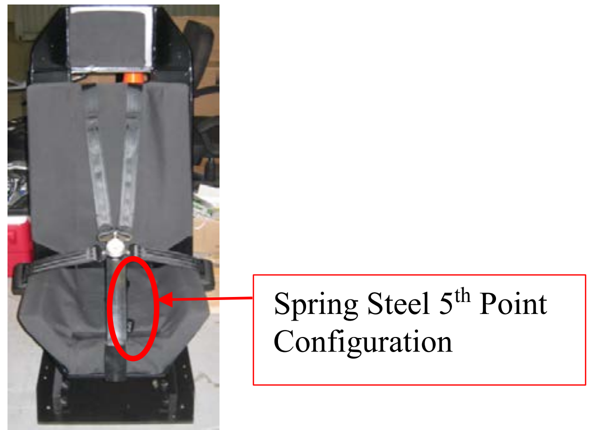

Figure 6: ReadyReach Initial Prototype, Spring Steel 5th Point

The second ReadyReach prototype utilized a production 5th point, which is utilized in a production military vehicle. The length and functionality of the buckle was unchanged from the production version. Figure 7 highlights ReadyReach with the production 5th point variant in the donned position.

Figure 7: ReadyReach Initial Prototype, Production Fixed 5th Point

Ultimately, the restraint system configuration containing the ReadyReach system was preferred over a system that did not contain it. The restraint system was then transitioned to the design stage.

Effects of Encumbrance on a Restraint System

As the program progressed, it was clear that seating systems would not be available for testing and an alternate would be required for the restraint validation. As such, a steel structured seat utilized in Economic Commission for Europe Regulation 16 (ECE R16) testing had to be utilized. The utilization of this seat would result in the "worst case" scenario for the restraint system, since the seating system would not dissipate any energy during the testing event. The energy of the entire crash event is therefore channeled through the restraints and their respective mounts. Whereas testing with an actual seating system would reduce the amount of energy that would otherwise be completely transferred to the restraint system.

The implementation and utilization of a pulse would prove to be challenging. Up until the inception of this program, a defined standard and crash pulse was not available. Though tests were conducted for research purposes, no certification had been conducted. As such, the OCP TECD team analyzed various FMVSS, SAE, previous tests and other organizational testing methods in addition to Modeling and Simulation (M&S). Upon evaluation, the team decided to utilize an accelerative pulse based on an M&S evaluation, which best represent a military vehicle. Figure 8 highlights the pulse created for the OCP TECD program.

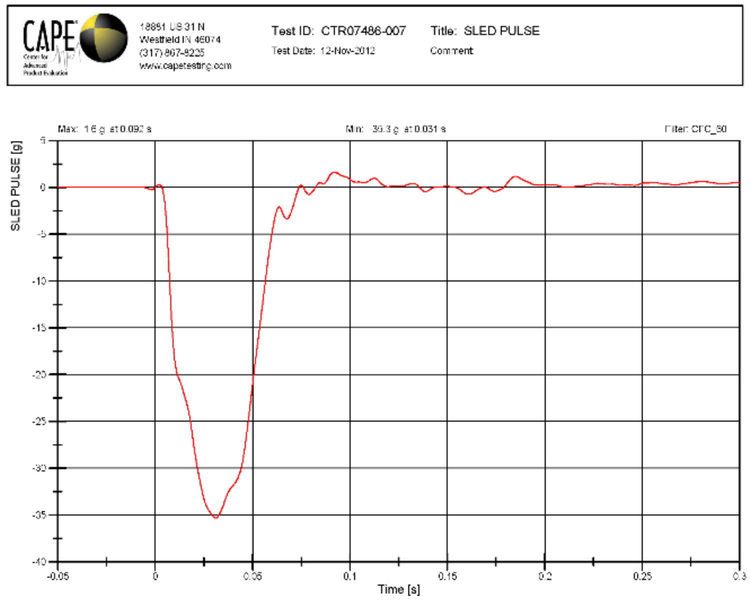

Figure 8: TARDEC DEVELOPED OCP TECD PULSE

At this time Soldier encumbrance was being prepared for utilization during testing. It was decided that the SAW Gunner PPE configuration was the heaviest available PPE set in the field weighing approximately 30kg. This gear set was utilized for the entirety of the OCP TECD restraint development program.

A pulse study was conducted to evaluate how the FMVSS 208 Section 13 pulse compared to the pulse developed for OCP TECD. The study showed that the FMVSS 208 Section 13 Pulse caused the timing of the injuries to shift and have lower magnitudes. Kinematics of the ATD during the FMVSS 208 Section 13 test did not have a significant impact on reducing neck and chest reactions in the encumbered occupant scenario. Additionally restraint loads increase as the crash pulse is made more aggressive.

Proper Restraint System Routing Procedures

During initial sled tests, it was discovered that restraint routing was crucial in the performance of the restraint system. When not placed properly the restraint system would slide off the gear, causing the load to drop and lose restraint. When the restraints began loading the occupant, again it caused a spike in the occupant injury load channels and was most evident in the restraint load cells. A set of guidelines were developed for the placement of restraints that ensured that optimal restraint was provided to the occupant. The procedure was soon instituted Army wide, seat and restraint manufacturers and throughout the testing community.

The encumbrance study found that the added mass and bulk has an effect on the occupant. Gear itself can become damaged and load anomalies may exist when the restraints are not routed properly. The chest displacement increases as the gear pushes rearward on the occupant, the armor plates load the entire chest. The neck extends as the necks reaches full rotation forward, this causes an increase in Neck Force in the Z direction (FZ) and Neck Moment in the Y direction (MY) vs a non-encumbered ATD.

IP Study

The IP study / impact surface study showed that the design was capable of transferring load through the femurs. This was apparent by the decreases in the chest and neck. Head acceleration increased, chest displacement decreased, and pelvis acceleration increased. In the videos, it is apparent that the hands contacted the IP and some of the load may have been carried by the arms contributing to a decrease in chest deflection.

Program Transition

The restraint system development and evaluation allowed various studies to be conducted concurrently. As such a pulse comparison, an encumbrance study, and an IP design study was conducted specifically focused on military occupant protection applications. Since these types of studies were not evaluated previously, it was crucial that this type of evaluation was conducted. The overarching purpose was to foster continual development in the field of military safety. Implementation of this restraint system was accomplished successfully by attaching restraints to a production MedEng seat that included the ReadyReach feature in addition to a ruggedized retractor system. Final vehicle level blast testing conducted in July 2015 performed to the design intent.

Organization of the Dissertation

This dissertation combines all of the research into the OCP TECD restraint system developed at TARDEC. Chapter 2 presents the U. S. Army Soldier Restraint System Evaluation Feedback for Optimal Warfighter Restraint System Designs. The third chapter presents Optimal Restraint System Routing Procedures for Restraint System Development. Chapter 4 presents The Effects of Soldier Gear Encumbrance on Restraints in a Frontal Crash Environment. The fifth chapter presents the IP Design and Evaluation on an Encumbered Soldier in a Frontal Crash Environment. The sixth chapter presents Future System Level Design and System Level Testing Considerations for Military Vehicles. These research papers were published in DTIC, SAE, ASME, and GVSETS in addition to being presented here in this dissertation.

Chapter 2

U.S. Army Soldier Restraint System Evaluation Feedback for Optimal Warfighter Restraint System Designs[1]

Executive Summary

This work was based on the OCP TECD program, specifically focusing on the Soldiers restraint system usage throughout the Army. The overriding technical challenge was to address the usage of restraint systems Army-wide and increase the percentage of overall usage. The study was accomplished through a restraint system User Evaluation conducted and funded by GSS, United States Army TARDEC, Warren, MI in cooperation with the Human Factors Department, NSRDEC, Natick, MA and Primus Solutions, Inc., Sterling Heights, MI

The perception of the U.S Army Soldier in regards to restraint systems is that utilizing them will hinder a Soldiers ability to respond during combat and/or emergency egress situations. In addition, restraint systems can hinder the performance of mission duties, be incompatible with gear, and difficult to don and doff. Therefore GSS collaborated with restraint system vendors and developed restraint systems that were representative of what is found in the operational environment (home and abroad) in addition to novel concepts, which address usability and comfort these systems were then presented to Soldiers at the events stated above.

The objective of the restraint System User Evaluation was to allow Soldiers to evaluate 10 restraint system concepts, form opinions, and evaluate the acceptability and desirability of each style of seat restraint system based upon a set of human factors characteristics: 1) belt accessibility, 2) buckle accessibility, 3) perceived ability to egress quickly and without error in combat situations, 4) ease of ingress and general operation, 5) comfort, 6) and likelihood of using the restraint system regularly in theater.

[1] "Karwaczynski, S., "26280, U.S. Army Soldier Restraint System Evaluation Feedback For Optimal Warfighter Restraint System Designs", DTIC, http://dtic.mil/dtic/, (2015) "

The Soldiers provided real time feedback for the restraint systems provided in this evaluation. It was deemed that the systems that contained the ReadyReach system within them were more likely to be worn. When these restraints were combined with retractors located at the hips and shoulders, the Soldiers were able to readily access the restraints and don them regardless of, which gear set they wore. Based on the evaluations provided within this report, it was clear that the Soldiers preferred and felt more comfortable with the ReadyReach equipped shoulder and lap retractors.

Introduction

The United States Army employs various types of vehicles to perform tactical, logistical and peacekeeping related operations. Vehicle sizes and weights range accordingly as required by the mission. Each of these vehicles are susceptible to Blast, Crash, Roll Over, and other Injury Causing events. As such, the mission of the Ground Systems Survivability Department is to counteract these events and help protect the Soldiers as they perform their required mission.

The performance of the stated military vehicles when subjected to Blast, Crash, Roll Over and other Injury Causing events will vary depending on vehicle size, weight, crush/energy absorbing structures and devices in addition to the under body shape and/or kit installed on the vehicle. In conjunction with these systems, a restraint system acts as a coupling mechanism to the energy absorbing seat, prohibiting or limiting the amount of relative motion the occupant has to the seat while limiting or eliminating occupant head contact to the roof and/or other hard surfaces in the vehicle, which are relatively close to the occupant as compared to a typical motor vehicle.

As Soldiers perform their missions they find themselves in vehicles that are not comfortable and do not allow much space for movement. In addition, surfaces in these vehicles are hard and rarely (if ever) contain energy absorbing interior surfaces that would allow the energy to be absorbed in case of an event. It is critical for the Soldiers to don their restraint system at all times regardless of comfort and/or annoyance.

The design of a new restraint system for military applications requires consideration of Soldier Gear (Encumbrance), Vehicle Interior Dimensional

Limitations (Either Legacy or New Platform) and Future Retrofits/Upgrades (Equipment and/or Entire Platform). In addition to providing a restraint system that is easy to don and doff, the system must be simple to use without training. If a restraint system is not intuitive to use, it has a lower probability of being utilized. Failing to take these considerations into account will result in the restraint system not being utilized or completely removed or cut out of the vehicle.

The United States Army Aeromedical Research Laboratory, Fort Rucker, AL conducted an investigation into fatalities associated with Roll Overs in the High Mobility Multipurpose Wheeled Vehicle (HMMWV). The report documented and presented the consequences for not utilizing restraint systems and showed that 69.2% of deaths identified could have been prevented if the Soldiers had worn their restraint system[4]. This report did not consider Blast, Crash, and Other Injury Causing events due to the sensitive nature. Fatalities associated with these other types of events produce similar outcomes when restraint systems are not worn. As such, a reduction in mortality and severity of injuries is associated with restraint system use.

Restraint System Comfort, Encumbrance and Usability Review Preparation

The restraint System Evaluation was created to allow Soldiers to easily identify restraint systems, which they would most likely utilize in the field. The systems were not limited to only advanced and novel restraint system concepts, instead current technologies, which the Soldiers are familiar with were added into the study to identify the biggest causes of discomfort and nonuse. As a base for the evaluation, the TARDEC Ground Systems Survivability Department reviewed systems typically found in both tracked and wheeled military vehicles. These systems are manually adjustable 4 or 5 point restraint systems containing no seat belt retractors within the assembly, as shown in Figure 9.

Figure 9: Manually Adjustable 4pt and 5pt Restraint Systems

With the Manually Adjustable restraint systems the possibility exists where the restraint systems sits loosely within the vehicle. When this occurs, the Soldiers could kick, sit on, or move the restraints out of the way since they may be perceived as an annoyance when they try to sit in a seat. Due to a wide range of sizes in the Soldier population, a manual restraint will likely need to be adjusted once a Solider occupies a seat. Figure 10 shows the varying shoulder restraints adjusted for large and smaller Soldier sizes. Additionally with Manually Adjusted restraint systems the lower restraints will loosely sit on the seat pan or hang over the seat and be on the floor, not being stowed in any manner as evident in Figure 10.

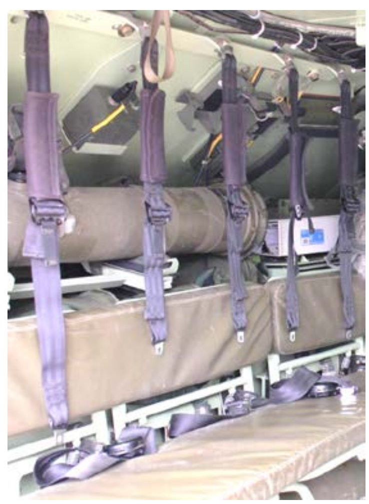

Figure 10: Manually Adjustable Restraint Systems Hang Loosely in a Military Vehicle

When the Soldier is fully outfitted with his gear set the range of motion of his arms, torso, and legs becomes limited. The weight of these gear sets can range from 20kg to 30kg depending on the Soldiers mission/position within the squad. This encumbrance can limit the Soldiers ability to reach behind him to access his Shoulder restraints and reach around the pouches located on his waist to access the Hip restraints and 5th Point restraint (if the system contains a 5th point). The encumbrance can contribute to an additional perception of annoyance, as the Soldier is now relatively bigger in size and weight. A 50th Percentile Male becomes approximately a 95th Percentile Male when encumbered with gear as seen in Figure 11.

Figure 11: Shows Digital Human Models (DHM) and Hybrid 3 (HIII) based on Current Soldier Populations and Anthropomorphic Test Dummy Models in a Seated Position

To help address the issue of stowage and eliminate the annoyance related to restraint systems hanging loosely inside the vehicle, the restraint system manufacturers have opted to move towards restraint systems that incorporate seat belt retractors in their designs. The advantage of these systems is that the restraint system becomes stowed and no longer presents this annoyance. However, a new annoyance emerges with a restraint system that incorporates restraint system retractors. By completely retracting the webbing and latch plates (tongues), the Soldier now has even less of the restraint system available to grasp to don it.

Though the restraint system containing retractors improves the ability to don and doff the restraint system, some issues still arise. In particular, a Soldier that is wearing his gear set may have a harder time reaching behind or below him to access his restraint system as illustrated in Figure 12. As such, it may take a Soldier longer to don his restraint system or even worse he may not wear it at all.

Figure 12: A male wearing Soldier gear attempting to don a Restraint System mounted at the shoulder on a retractor

TARDEC Ground Systems Survivability Department is dedicated to developing new restraint Technologies that allow for integration into current and future platforms. Systems such as those incorporating restraint presenting systems (presenters) may be integrated sooner thus increasing usage and comfort while maintaining a reasonable price point. Expanding current restraint systems and developing Novel restraint systems, which will include systems that provide the Soldier with easier access are being developed and will continue development by the TARDEC Ground Systems Survivability Department through core funding and SBIR funding opportunities.

Restraint System Evaluation

To understand restraint usage among Soldiers better, the GSS Department assembled unique seats containing variations styles of restraint systems. The restraint systems consisted of manual, retractable, automatic, and novel designs. Each restraint system was attached to the same type of seat with the proper restraint mounting accommodations, which were common across all of the seats, therefore removing the anchor and routing variations between units. Comfort and seat functionality were not evaluated during this study. Given that each seat was identical, no variability had to be factored into the restraint system comfort ratings. Two evaluations were run throughout the fiscal years. Each evaluation was conducted the same way. The only differing factor was the final evaluation, which utilized a single-design restraint system similar to the

6A and 6B restraint system designs. The Government ran four evaluations. The Contractor (IMMI) ran an independent study at their design center with employees who were active military members to help refine their concept.

Initial Restraint System Evaluation

Methodology

Test Participants

The twenty-five participants ranged in ages (between 19 and 29) and weight (from 140 pounds to 230 pounds with a mean weight of 181 pounds). PPE configuration styles ranged from fire team leaders, rifleman, and drivers. Deployment zones included Korea, Iraq, and Afghanistan. Gear set configurations were consistent for the assigned Soldier position; however it was discovered that no two Soldiers utilize the exact same gear set configurations. Instead each Soldier utilized a configuration, which was most suitable to his or her needs, examples being additional add-on pieces, reconfigured ammo round locations and aftermarket accessories. However, different Soldiers will configure their gear and still be proficient in utilizing it and accessing it. This presents a challenge for this evaluation and for restraint system evaluations as a whole. The restraint system routing can contribute to reduced effectiveness when presented with a Blast, Crash, or Roll Over situation.

Apparatus

Seven generic seats were modified to accommodate various seat restraint systems. All of the seats with the exception of the first seat had their own unique restraint system mounted onto them. Seat 1 (contained restraint system variations 1A, 1B, and 1C) allowed for a quick and efficient swap out of manual adjust restraints. The use of only one seat for this configuration was controlled by the fact that additional generic seats were not available. In total ten restraint systems were evaluated on seven generic seats. The various restraint systems contained various buckle designs, retractor designs, various presenters, motorized systems, and a conceptual roller coaster restraint system. Table 5 and Figure 13 summarize the entire restraint system set. Figure 14 through Figure 23 summarize system level descriptors for each restraint system.

Restraint System Designs

Table 5: Restraint System Designs

1A: Steel cable mounted AMSAFE rotary buckle
1B: Pilot Buckle featuring a shoulder belt release button
1C: Rotary buckle with slide on shoulder belt attachment
2: Butterfly buckle featuring reduced dexterity release with shoulder retractors and fixed lap belt
3: Takata Thumb tab release rotary buckle with 5-point retractors (shoulder, lap, crotch)
4: AutoFlug buckle with pull strap release featuring channel tongue insertion sleeved presenters
5: Takata thumb tab release rotary buckle with automatic pre-tensioner system
6A: IMMI thumb tab release with 5-point retractors featuring ReadyReach presenters
6B: IMMI rotary buckle with 5-point retractors featuring ReadyReach presenters
7: TARDEC Roller Coaster Restraint Prototype

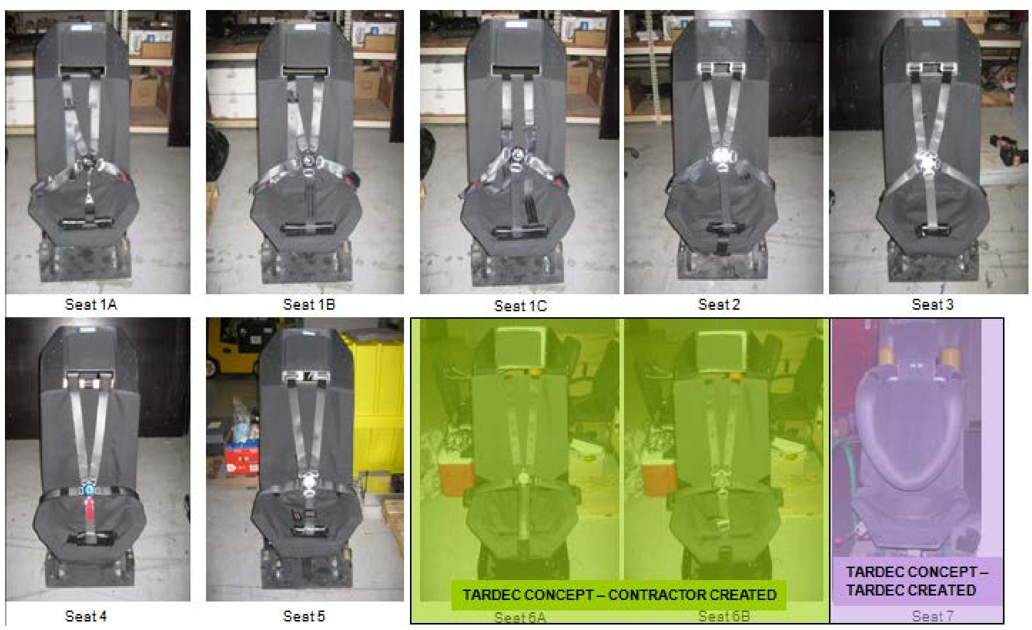

Figure 13: Photos of Seating Systems with Integrated Restraint Systems

SEAT 1A – STEEL CABLE MOUNTED AMSAFE ROTARY BUCKLE

Figure 14: Photo of Seat 1A- Steel Cable Mounted AMSAFE Rotary Buckle

Seat restraint 1A used a manual system featuring a steel cable mounted AMSAFE Rotary Buckle. The seat consisted of the following:

1. The buckle is mounted onto a steel cable, the steel cable provides stiffness, and an upright orientation at all times. The remainder of the seat belt is manually adjustable with hard point anchors.
2. The buckle is a rotary style with finger divots at the distal end and one thumb divot at the proximal end.
3. The buckle assembly minus the rotary cover utilizes the corporate AmSafe buckle design found on many of their product lines familiar to the military.

SEAT 1B – AMSAFE PILOT BUCKLE FEATURING A SHOULDER BELT RELEASE BUTTON

Figure 15: Photo of AMSAFE Pilot Buckle Featuring a Shoulder Belt Release Button

Seat restraint 1B used a restraint system featuring an AMSAFE Pilot Buckle with a shoulder belt release button. The restraint characteristics consisted of:

1. The two shoulder straps release independently from the lap belts with the press of a concealed button for improved comfort in various terrains.
2. The buckle release is a rotary style with nine finger divots.
3. The seat belt is manually adjustable with hard point anchors.
4. The buckle assembly minus the rotary cover utilizes the corporate AmSafe buckle design in addition to a secondary concealed latch plate for the independent release of the shoulder straps.

SEAT 1C- ROTARY BUCKLE WITH SLIDE ON SHOULDER BELT ATTACHMENT

Figure 16: Photo of Seat 1C- Rotary Buckle with Slide on Shoulder Belt Attachment

Seat restraint 1C used a system featuring an AMSAFE rotary buckle with slide on shoulder belt attachments. The characteristics of this seat restraint included:

1. The shoulder belts have a slide-through-tongue feature where they must be slid unto the lap buckles before buckling.
2. The latch plates for the lap are the only two latch plates, which slide into the buckle (not including the crotch point, which is fixed to the buckle.
3. The seat belt is manually adjustable with hard point anchors.
4. The buckle assembly including the rotary cover utilize the corporate AmSafe buckle design found on many of their product lines familiar to the military.

SEAT 2- AMSAFE REDUCED DEXTERITY BUCKLE RELEASE WITH SHOULDER RETRACTORS AND FIXED LAP BELTS

Figure 17: Photo of Seat 2 AMSAFE Reduced Dexterity Buckle Release with Shoulder Retractors and Fixed Lap Belts

The Seat restraint 2 used a system featuring an AMSAFE reduced dexterity buckle release with shoulder retractors and fixed lap belts. The characteristics of this seat restraint included:

1. The buckle assembly has two flat members (resembling wings of a butterfly) that pull away from the occupant, this motion allows for the buckle to release all of the latch plates at once. This feature is intended for occupants that have reduced dexterity in their hands resulting from injury.
2. The webbing for the shoulder belts is mounted onto retractors, which retract the webbing out of the way for ingress and egress in addition to providing an automatic mechanical adjustment of the shoulder belts when they are being utilized. The remaining seat belts are manually adjustable with hard point anchors.
3. The buckle assembly minus the cover and latch plates use the corporate AmSafe design found on many of their product lines familiar to the military.

SEAT 3- TAKATA THUMB TAB RELEASE ROTARY BUCKLE WITH 5-POINT RETRACTORS (SHOULDER, LAP, AND CROTCH)

Figure 18: Photo of Seat 3 Takata Thumb Tab Release Rotary Buckle with 5-point Retractors

The Seat 3 used a restraint system featuring a Takata thumb tab release rotary buckle with 5-point retractors. The characteristics of this restraint system include:

1. The webbing for the shoulder belts, lap belts, and crotch belt are mounted onto retractors, which retract the webbing out of the way for ingress and egress in addition to providing an automatic mechanical adjustment of the shoulder belts when they are being utilized.
2. The buckle assembly utilizes the corporate Takata design found on many of their product lines.

SEAT 4- AUTOFLUG BUCKLE WITH PULL STRAP RELEASE FEATURING CHANNEL TONGUE INSERTION SLEEVED PRESENTERS

Figure 19: Photo of Seat 4 Autoflug Buckle with Pull Strap Release Featuring Channel Tongue Insertion Sleeved Presenters

Seat restraint 4 used a system featuring an Autoflug Buckle with Pull Strap Release Featuring Channel Tongue Insertion Sleeved Presenters. The characteristics of this seat restraint include:

1. The buckle and tongue assembly feature tongues, which can be inserted into the buckle via a channel. When locked the channel does not allow the latch plates to release. Unlike other buckle assemblies, a prescribed location does not exist. Example being: A competitor's latch plate has to be inserted at the 3:00, 9:00, 11:00, and 1:00 position, whereas the latch plates on this system must be inserted near the typical clock orientation. The latch plates self-adjust once the occupant has moved and become comfortable in the seat.
2. The buckle assembly includes a pull tab (strap), which when pulled away from the occupant disengages the latch plates allowing for faster egress.
3. The latch plates are unique to this buckle only, and will only work with a

mating channel in the buckle.

4. The webbing at the shoulder and lap positions feature plastic sleeves, which are intended to keep the webbing erect in the seat once the occupant had egressed, thus being ready for the next occupant.
5. The webbing for the shoulder belts and lap belts are mounted onto retractors, which retract the webbing out of the way for ingress and egress in addition to providing an automatic mechanical adjustment of the shoulder belts when they are being utilized. The crotch belt is manually adjustable with hard point anchors.

SEAT 5- TAKATA THUMB TAB RELEASE ROTARY BUCKLE WITH AUTOMATIC PRE-TENSIONER SYSTEM

Figure 20: Photo of Seat 5 Takata Thumb Tab Release Rotary Buckle with Automatic Pre-Tensioner System

Seat restraint 5 used a system featuring a Takata Thumb Tab Release Rotary Buckle with Automatic Pre-Tensioner System. The characteristics of this seat restraint include:

1. The buckle assembly has raised members located, which allow for system unlatching utilizing only the thumb.
2. The webbing for the shoulder belts and lap belts are mounted onto electro-mechanical retractors, which retracted the webbing out of the way for ingress and egress in addition to providing an automatic mechanical adjustment of the shoulder belts when they are being utilized. The crotch belt is manually adjustable with hard point anchors.
3. The electro-mechanical retractors, when coupled to the sensing system, provide signals to tighten the restraint system in the event of a blast, crash, or rollover event in addition to off road situations where the occupant may become out of position the system will apply tension to the webbing to retain the occupant in place.

4. The buckle assembly is the corporate Takata design found on many of their product lines; however, additional features have been added. The buckle has the ability to release the latch plates when a signal is sent to an internal mechanism. This system can be activated during an emergency, in addition should the vehicle cab fill with water the water sensors also send a release signal.

SEAT 6A- IMMI THUMB TAB RELEASE WITH 5-POINT RETRACTORS FEATURING READYREACH PRESENTER

Figure 21: Photo of Seat 6A IMMI Thumb Tab Release with 5-point Retractors Featuring ReadyReach Presenter

Seat restraint 6A used a system featuring an IMMI thumb tab release with 5-point retractors featuring ReadyReach Presenters. The characteristics of this seat restraint include:

1. The buckle assembly features tall tabbed members, which allow for easier system unlatching, which can be accomplished by utilizing only the thumb.
2. The webbing for the shoulder belts and lap belts are mounted onto retractors, which retracted the webbing out of the way for ingress and egress in addition to providing an automatic mechanical adjustment of the shoulder belts when they are being utilized. The crotch belt is a fixed length (not manually adjustable) with hard point anchors
3. The webbing for the shoulder belts and lap belts contain a web-stiffening device referred to as "ReadyReach", which, when not being utilized would stay erect and out of the way for ingress and egress. When the occupant sits in the seat, he could simply grab the webbing at his shoulders and lap, and

latch it into the buckle. When being pulled out of the retractors and buckled the ReadyReach does not interact with the shoulders or lap and bend out of the way.

4. The crotch belt also utilizes the ReadyReach design in addition to a plastic sleeve. The ReadyReach allows the crotch belt to be tilted down and out of the way for egress and tilted upward once the occupant is seated in the seat. The crotch belt stays erect in place allowing the occupant to buckle the latch plates
5. The buckle assembly utilizes the corporate IMMI design found on many of their product lines.

SEAT 6B- IMMI ROTARY BUCKLE WITH 5-POINT RETRACTORS FEATURING READYREACH PRESENTER

Figure 22: Photo of Seat 6B- IMMI Rotary Buckle with 5-point Retractors Featuring ReadyReach Presenter

Seat restraint 6B used a system featuring an IMMI thumb tab release with 5-point retractors featuring ReadyReach Presenters. The characteristics of this seat restraint include:

1. The buckle release is a rotary style with eight finger divots.
2. The webbing for the shoulder belts and lap belts are mounted onto retractors, which retract the webbing out of the way for ingress and egress in addition to providing an automatic mechanical adjustment of the shoulder belts when they are being utilized. The crotch belt is manually adjustable with hard point anchors.
3. The webbing for the shoulder belts and lap belts contain a web-stiffening device referred to as “ReadyReach”, which, when not being utilized stay erect and out of the way for ingress and egress. When the occupant sits in the seat he could simply grab the webbing at his shoulders and lap, and latch it into the buckle. When being pulled out of the retractors and buckled the

ReadyReach does not interact with the shoulders or lap and bends out forward of the occupant when not in use.

4. The buckle assembly is the corporate IMMI design found on many of their product lines.

SEAT 7- ROLLER COASTER RESTRAINT

Figure 23: Photo of Seat 7 Roller Coaster Restraint

Seat restraint 7 used a roller coaster style restraint system. The features of this seat restraint are as follows:

1. The design consists of an over the shoulder roller coaster type restraint.
2. The bar is adjustable upward and downward (to accommodate shoulder comfort) and fore and aft (to accommodate occupant gear set size).
3. An emergency release is located near the pan of the seat, the lever can be pulled to release the system.

Procedure

Twenty-five Soldiers evaluated 10 restraint systems attached to seven identical seats over two days. A generic set of seats containing the restraint systems were placed around the boarder of a room facing the wall at a fixed distance (roughly 0.6m or 2 feet) to best emulate the constraints of a military vehicle.

Upon entering, each Soldier completed a demographics form as shown in Appendix A. They described their rank, their deployed position, vehicles with which they have experience, if they typically wore their seatbelts while deployed, if they had any problems with seatbelts, and if they had been in any vehicle incidents while in service.

After completing the demographics section, each Soldier was asked to ingress and egress out of each restraint system without any assistance or guidance. The order in, which the Soldiers evaluated each seat restraint was based on interviewer and seat availability. Upon completing egress, each Soldier was given a survey to fill out as shown in Appendix B**,** about the particular restraint system they just evaluated. The Soldier was then asked to evaluate the next available restraint system.

Once the Soldiers evaluated all the restraint systems, an interviewer would ask for their opinions on each restraint system design as shown in Appendix C. The Soldiers provided their satisfaction ranking for each restraint system and provided comments about each restraint system, what they would like to see in a restraint system, and shared their real world experiences as they related to restraint systems.

Results

The participants were asked to rate each of the 10 restraint systems using a survey with seven items. Each item was rated using a 5-point scale, with the exception of item 4, entanglement, which was rated using a 3-point scale. The survey is available in Appendix B. Data collected on the seven items for each of the 10 restraint systems were analyzed using repeated measures analysis of variance (ANOVA), with the ratings on each of the 7 items used as the within subjects factor. If a statistically significant result was obtained on the ANOVA, post hoc tests of all possible pairwise comparisons were made using a Bonferroni adjustment to reduce family-wise error. The results of the repeated measures ANOVAs for the initial restraint system evaluations are presented in Table 6, followed by individual tables for the descriptive statistics on the seven items.

Table 6: Repeated Measures ANOVA – Seat Restraint Evaluations

Seat Restraint Item	*DF*	*F*	*p*
Belt accessibility	9, 144	5.62	<.001
Buckle accessibility	9, 135	4.69	<.001
Egress	9, 171	2.98	.003
Entanglement: Did you experience	9, 153	1.87	.060
Overall ease of operation	9, 162	7.64	<.001
Comfort of restraint system	9, 171	1.98	.045
In theater, I would use this restraint . . .	9, 162	3.69	<.001

Statistically significant results were obtained for all of the items, except for entanglement. The results of the t-tests used to compare all possible pairwise comparisons for each of the seat restraint items are presented in Table 7 through Table 17.

Table 7: Descriptive Statistics – Belt Accessibility

Restraint Number	Mean	*SD*
1A	3.41	1.33
1B	3.53	1.28
1C	2.88	1.41
2	3.71	1.21
3	$3.76_{a,b,c}$	1.25
4	3.94	.97
5	3.71	1.49
6A	4.53_{a}	.80
6B	4.41_{b}	.62
7	4.59_{c}	.87

Note: cells with matching subscripts are statistically significantly different per post hoc tests using the Bonferroni adjustment

The results of the repeated measures ANOVA provided in Table 6 support that perceptions of belt accessibility differed significantly among the 10 types of restraints, $F\,(9, 11) = 5.62$, $p < .001$. In examining all possible pairwise comparisons, statistically significant differences were found between restraint 3 (M = 3.76, SD = 1.25) and restraint 6A (M = 4.53, SD = .80), restraint 6B (M = 4.41, SD = .62), and restraint 7 (M = 4.59, SD = .87). These findings provided support that the participants indicated that restraints 6A, 6B, and 7 were more accessible than restraint 3. The mean scores for the remaining restraints were not statistically significant.

Table 8: Descriptive Statistics – Buckle Accessibility

Restraint Number	Mean	*SD*
1A	3.81	1.17
1B	3.81	1.17
1C	3.06	1.53
2	3.81	1.28
3	4.25	.86
4	4.00	.89
5	3.75	1.34
6A	4.56	.73
6B	4.13	1.15
7	4.50	.82

Note: cells with matching subscripts are statistically significantly different per post hoc tests using the Bonferroni adjustment

The results of the repeated measures ANOVA provided in Table 6 for buckle accessibility differed significantly among the 10 types of restraints, F (9, 135) = 4.69, $p < .001$. In examining all possible pairwise comparisons among the 10 types of restraints, no statistically significant differences were found among the individual restraints.

Table 9: Descriptive Statistics – Egress

Restraint Number	Mean	*SD*
1A	$3.25_{a,b}$	1.07
1B	4.00	1.30
1C	3.55	1.28
2	3.80	1.11
3	4.00	.97
4	4.20_{a}	.89
5	3.80	1.32
6A	4.30_{b}	.86
6B	4.20	1.01
7	3.80	1.28

Note: cells with matching subscripts are statistically significantly different per post hoc tests using the Bonferroni adjustment

The results of the repeated measures ANOVA provided in Table 6 support that perceptions of egress differed significantly among the 10 types of restraints, F (9, 11) = 2.98, p = .003. In examining all possible pairwise comparisons, statistically significant differences were found between restraint 1A (M = 3.25, SD = 1.07) and restraint 4 (M = 4.20, SD = .89) and restraint 6A (M = 4.30, SD = .86). Based on these findings, it appears that participants were more likely to prefer seat restraint 4 and 6A to seat restraint 1A. The mean scores for the remaining restraints were not statistically significant.

Table 10: Descriptive Statistics – Entanglement

Restraint Number	Mean	*SD*
1A	2.39	.70
1B	2.78	.43
1C	2.50	.62
2	2.67	.59
3	2.83	.38
4	2.56	.70
5	2.78	.55
6A	2.83	.38
6B	2.78	.55
7	2.83	.38

Note: cells with matching subscripts are statistically significantly different per post hoc tests using the Bonferroni adjustment

The results of the repeated measures ANOVA provided in Table 6 support that perceptions of entanglement did not differ significantly among the 10 types of restraints, $F\ (9, 153) = 1.87$, $p = .060$. Based on this finding, there does not appear to be any significant differences when comparisons are made with the other nine types of restraints.

Table 11: Descriptive Statistics – Ease Of Operation

Restraint Number	Mean	*SD*
1A	3.84_{a}	1.17
1B	3.95_{b}	.91
1C	$2.47_{a,b,c,d,e,f,g,h,i}$	1.07
2	3.84_{d}	1.17
3	4.00_{e}	1.15
4	3.68	1.25
5	3.79_{f}	1.40
6A	4.16_{g}	.90
6B	4.21_{h}	.98
7	4.32_{i}	1.11

Note: cells with matching subscripts are statistically significantly different per post hoc tests using the Bonferroni adjustment

The results of the repeated measures ANOVA provided in Table 6 support that perceptions of ease of operation differed significantly among the 10 types of restraints, F (9, 162) = 7.64, $p < .001$. The results of the pairwise comparisons among the 10 types of restraints provided evidence of statistically significant differences between restraint 1C (*M* = 2.47, *SD* = 1.07) and restraint 1A (*M* = 3.84, *SD* = 1.17), restraint 1B (*M* = 3.95, *SD* = .91), restraint 2 (*M* = 3.84, *SD* = 1.17), restraint 3 (*M* = 4.00, *SD* = 1.15), restraint 5 (*M* = 3.79, *SD* = 1.40), restraint 6A (*M* = 4.16, *SD* = .90), restraint 6B (*M* = 4.21, *SD* = .98), and restraint 7 (*M* = 4.32, *SD* = 1.11). Restraint 4 (*M* = 3.68, *SD* = 1.25) did not differ from restraint 1C. These findings provided evidence that seat restraint 1C was the least preferred restraint.

Table 12: Descriptive Statistics – Comfort of Restraint System

Restraint Number	Mean	*SD*
1A	3.90	1.02
1B	4.15	.81
1C	3.65	1.04
2	4.20	.95
3	4.00	.86
4	4.15	.99
5	3.75	1.12
6A	4.05	.89
6B	4.30	.86
7	4.15	.88

Note: cells with matching subscripts are statistically significantly different per post hoc tests using the Bonferroni adjustment

The results of the repeated measures ANOVA provided in Table 6 support that perceptions of the comfort of the restraint systems differed significantly among the 10 types of restraints, F (9, 171) = 1.98, p = .045. The results of the pairwise comparisons among the 10 types of restraints provided no evidence of statistically significant differences among the 10 restraints.

Table 13: Descriptive Statistics – In Theater, I Would Use this Restraint

Restraint Number	Mean	*SD*
1A	3.05	1.39
1B	3.42	1.39
1C	2.58_a	1.26
2	3.53	1.26
3	3.53	1.07
4	3.47	1.31
5	3.00	1.37
6A	3.84_a	1.12
6B	3.84	1.12
7	3.42	1.50

Note: cells with matching subscripts are statistically significantly different per post hoc tests using the Bonferroni adjustment

The results of the repeated measures ANOVA provided in Table 6 support that perceptions of the comfort of the restraint systems differed significantly among the 10 types of restraints, F (9, 162) = 3.69, $p < .001$. The results of the pairwise comparisons among the 10 types of restraints produced a statistically significant difference between restraint 1C (M = 2.58, SD = 1.26) and restraint 6A (M = 3.84, SD = 1.12). These findings indicated that the participants preferred seat restraint 6A more than 1C. The remaining pairwise comparisons were not statistically significant.

Ideal Restraint Fit Assessment

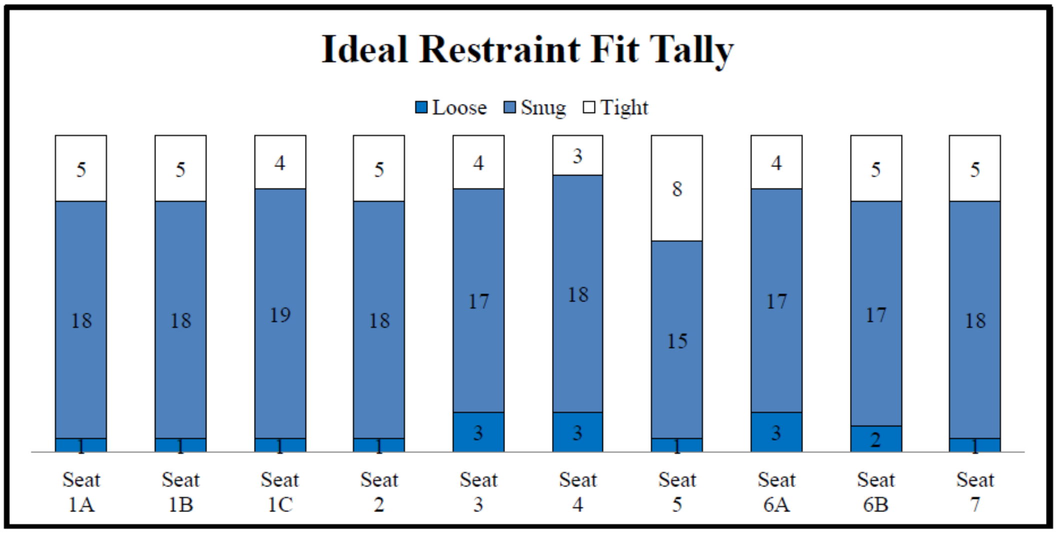

Figure 24: Initial System Design Ideal Restraint Fit Chart

Within each seat configuration, an ideal restraint Fit was evaluated to determine how the occupant would want the restraint to contact their body. Regardless of system design (Fixed Restraints, Retractor Mounted or Roller Coaster), Restraint fit was varied to emulate the Loose, Snug and Tight conditions. This evaluation was less focused on the Restraint subset and more so onto the webbing and buckle interface combinations. As shown in Figure 24 the majority of the occupants preferred a snug fit for all seat restraint systems. Seat 5, the motorized retractor, had the lowest number of "snug" ratings, with 8 occupants preferring a tight fit. A loose fitting system was not preferred.

Would you use this system assessment.

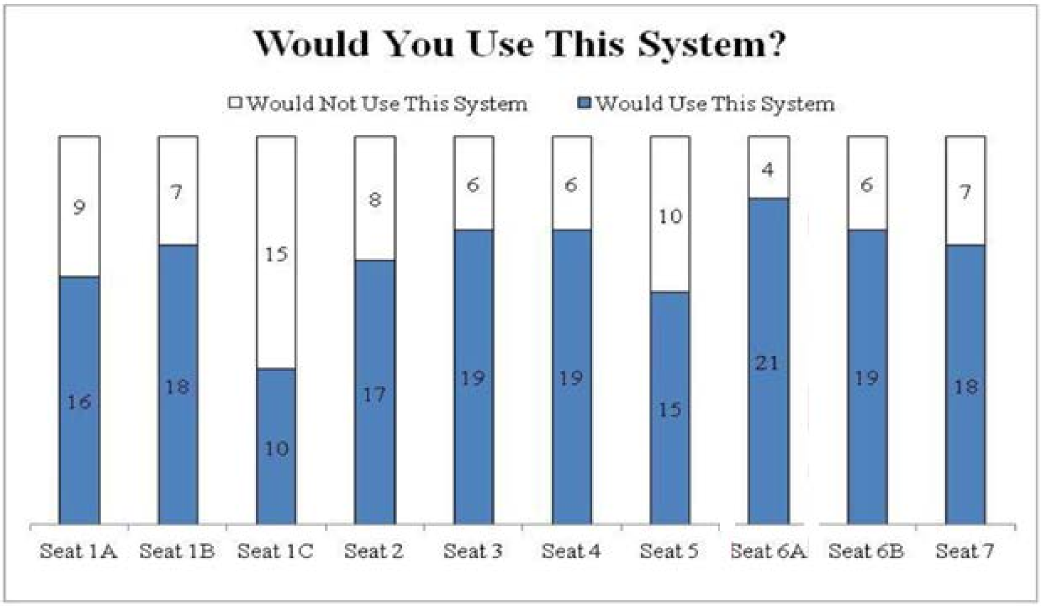

Figure 25: Initial System Design Utilization Chart

Within each seat, configuration usability was evaluated to determine how likely an occupant would utilize a particular restraint system. As shown in Figure 25, the restraint system that had the higher number of affirmative responses was 6A, with restraint system 1C having the least number of affirmative responses. All of the seat restraints had more than 50% positive responses with the exception of seat restraint 1C.

Discussion

The data gathered from the initial restraint system evaluation was utilized to determine the best possible system for use. Statistically significant differences were found in belt accessibility, egress, and ease of operation related questions. The systems, which proved most favorable and downselected for further developed were 6A and 6B, both variations containing the ReadyReach systems with retractors.

Belt accessibility favored the ReadyReach systems (6A and 6B) and the novel roller coaster system (7), these designs particularly focused on having the restraints available for easy accessibility as compared to system 3. System 3 did not have any systems to facilitate better belt accessibility and had retractors mounted on all five points, as compared to systems 6A and 6B, which had fixed fifth points. When system 3 retracted the crotch point, it was very difficult for the Soldiers to access it, while the fixed restraints on 6A and 6B were intuitive and much easier to find and don. Alternately system 7 had a single bar assembly assisted by a spring, the bar always presented itself above the Soldier making it easy to access.

The ease of egress was enhanced by providing retractors, systems 4 and 6A both feature retractors and allow the webbing to be retracted allowing the Soldier to egress efficiently as compared to system 1A, which was a manual system. System 4 featured a buckle system, which, when pulled forward released all points (with the exception of the 5^{th} point) this allowed the retractors to quickly retract the system. System 6A utilized the ReadyReach system coupled with retractors allowing the webbing to be retracted fully allowing for easier egress. System 1A being completely manual did not feature retractors, instead the webbing was fixed and did not move out of the way for the Soldiers to egress

The ease of operation of one particular restraint system was very low. This system being 1C. The particular system required Soldiers to loop the tongue of the lap belt through the tongue located on the shoulder belt. Many Soldiers tried to force the tongue into the shoulder slot, many other Soldiers asked for assistance donning the restraint. The overall usability of this restraint was low.

System 6A was selected as one of the restraint systems, which rated highly in the “In theater, I would Use this restraint “category. The ReadyReach system coupled to the retractors and fixed fifth point provided a system, with which the Soldiers felt most comfortable. Additionally Soldiers were asked their restraint fit preference (Loose, Snug or Tight) as it related to the each restraint system, this feedback was subjective and utilized to understand retractor system spring forces as they relate in general to military restraint system programs and not directly related to the OCP TECD program.

A final question was asked in regards to whether or not Soldiers would actually utilize a particular restraint system. Given the available designs in the restraint evaluation, the positive rating towards the ReadyReach design supported the decision to develop the system further. Even though the data would suggest that the other restraint systems would possibly be utilized as well, the programmatic decision would ultimately steer the design decision. With the progression of the OCP TECD program, it was decided that the ReadyReach system was the best choice for integration. As the OCP TECD program progressed a seat design was selected and the restraint system containing the ReadyReach was further refined. This refinement resulted in the finalized restraint system, which was evaluated by Soldiers in a representative vehicle.

Secondary System Review - Finalized System Design for OCP TECD

Methodology

Test Participants

The twenty-two participants ranged in ages (between 19 and 29) and weight (from 140 pounds to 230 pounds with a mean weight of 179 pounds). PPE configuration styles included vehicle commanders, tank commanders' fire team leaders, rifleman, drivers, grenadiers, and other various participants as listed in the Appendix D. Deployment zones included Iraq and Afghanistan. As with the prior study, gear set configurations were consistent for the assigned Soldier position, however it was discovered that no two Soldiers utilize the exact same gear set configurations. Instead, each Soldier utilized a configuration that was most suitable to his or her needs, examples being additional add-on pieces, reconfigured ammo round locations and aftermarket accessories. However, different Soldiers will configure their gear and still be proficient in utilizing it and accessing it. This presents a challenge for this evaluation and for restraint system evaluations as a whole. The restraint system routing can contribute to reduced effectiveness when presented with a Blast, Crash, or Roll Over situation.

Apparatus

An interior vehicle demonstrator was developed for the OCP TECD program and utilized for Soldier evaluations, interior evaluations, site visits, trade shows, and various other Army related functions. This system replicated the entire vehicle interior environment, which included: seats (with restraints), cargo retention features and various equipment. Being an exact replica of the actual vehicle interior, provided a realistic environment in, which evaluations and reviews could be performed. The entrance ramp and outer shell of the demonstrator is shown in Figure 26, with Figure 27 showing the demonstrator interior.

Figure 26: Entrance Ramp And Outer Shell Of The OCP TECD Demonstrator[5]

Figure 27: Interior Of The OCP TECD Demonstrator[6]

The OCP TECD restraint system is pictured in Figure 28 prior to being mounted onto the seat.

Figure 28: OCP TECD Restraint System Prior To Being Mounted Onto The Seat

The system level design is depicted in Figure 29 as it is fitted onto the OCP TECD Demonstrator vehicle. The occupant is able to don and doff the restraint system easily due to the available ReadyReach System.

Figure 29: ReadyReach Restraint System Static Position and Donned Position

Procedure

Twenty-two Soldiers evaluated the restraint system in the OCP TECD demonstrator vehicle. The demonstrator was located within a building and connected to a power supply system allowing the interior lights and air conditioning system of the demonstrator to operate. Before entering the demonstrator, each Soldier completed a demographics form as shown in Appendix D. They described their rank, their deployed position, vehicles with which they have experience, if they typically wore their seatbelts while deployed, if they had any problems with seatbelts, and if they had been in any vehicle incidents while in service.

After completing the demographics section, each Soldier was asked to ingress and egress out of the seating system without any assistance or guidance. The seat location in which the Soldiers evaluated the restraint was random and based on interviewer and seat availability. Upon completing egress, each Soldier was given a survey to complete about the restraint system (See Appendix E).

Once the Soldier evaluated the restraint system, an interviewer would ask for their opinions on the restraint system (See Appendix F). The Soldiers provided their satisfaction ranking for the restraint system and provided comments about them, what they would like to see in a restraint system, and shared their real world experiences as they related to restraint systems.

Results

Secondary System Review - Finalized System Design for OCP TECD

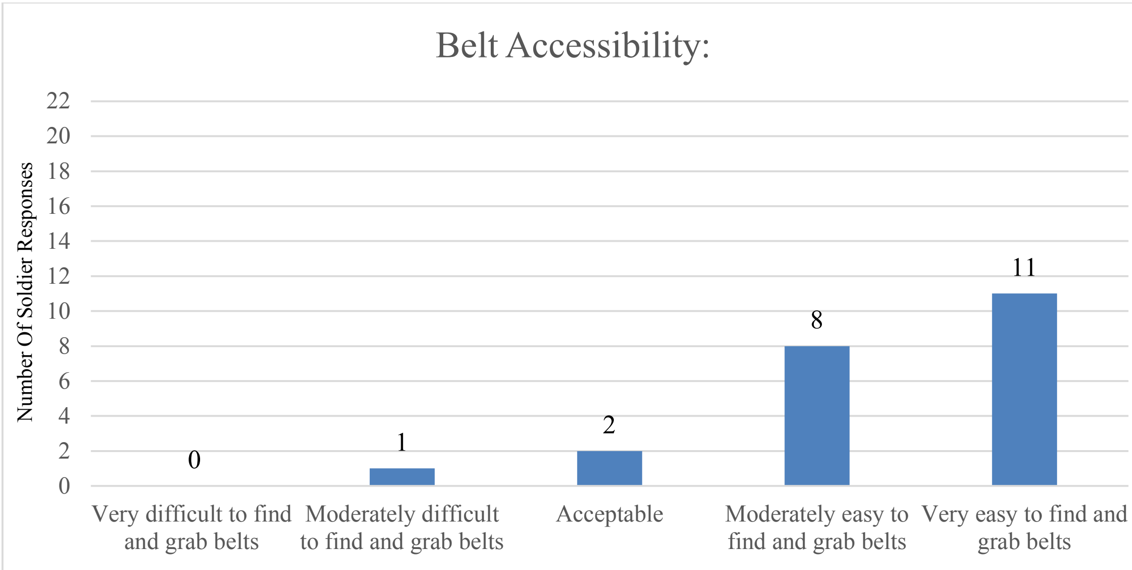

Figure 30: Secondary System Design Belt Accessibility Chart

The belt (webbing) accessibility was rated on a scale from 1 through 5. One (1) was the lowest rating, which would have been selected should the occupant determine that the Belt (webbing) was very difficult to don. Five (5) was the highest rating, which would be selected should the occupant determine that the belt (webbing) was very easy to don. As shown in Figure 30, 11 Soldiers concluded that the accessibility of the belt within the restraint system was very easy to find and grab. Eight Soldiers found the accessibility of the belts moderately easy to find and grab. Two Soldiers found it acceptable to find and grab the belts. One Soldier found it moderately difficult to find and grab the belts. None of the Soldiers found it very difficult to find and grab the belts.

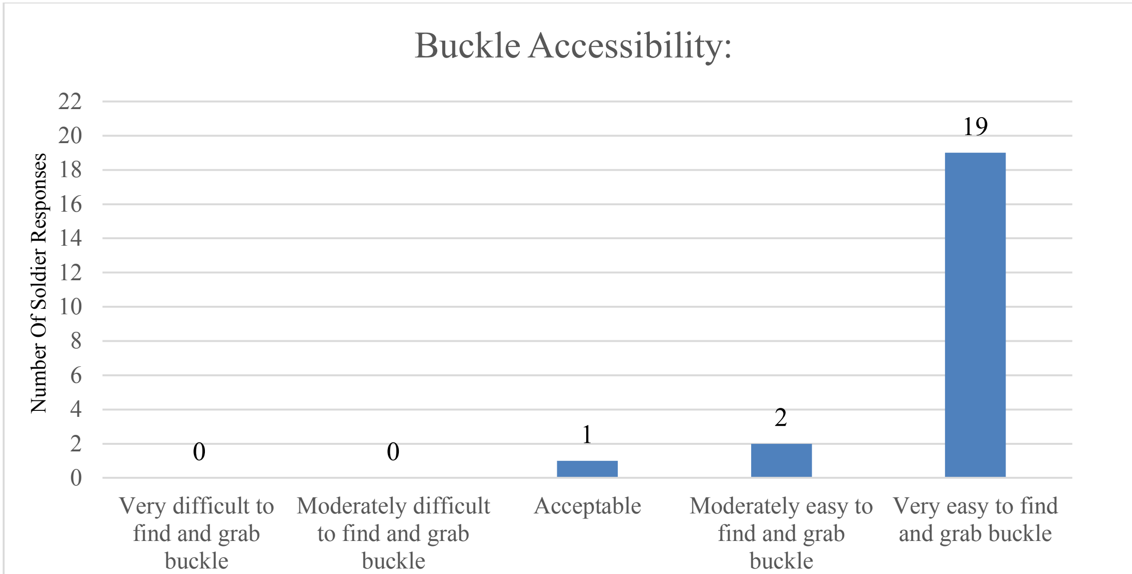

Figure 31: Secondary System Design Buckle Accessibility Chart

The buckle accessibility was rated on a scale from 1 through 5, with 1 the lowest rating that would have been selected if the occupant determined that the buckle was very difficult to find and don. The highest rating (5) would be selected if the occupant determined that the buckle was very easy to don. As shown in Figure 31, 19 of the Soldiers concluded that the accessibility of the buckle within the restraint system was very easy to find and grab. Two Soldiers found the accessibility of the buckle moderately easy to find and grab. One Soldier found it acceptable to find and grab the buckle. None of the Soldiers found it either moderately or very difficult to find and grab the buckle.

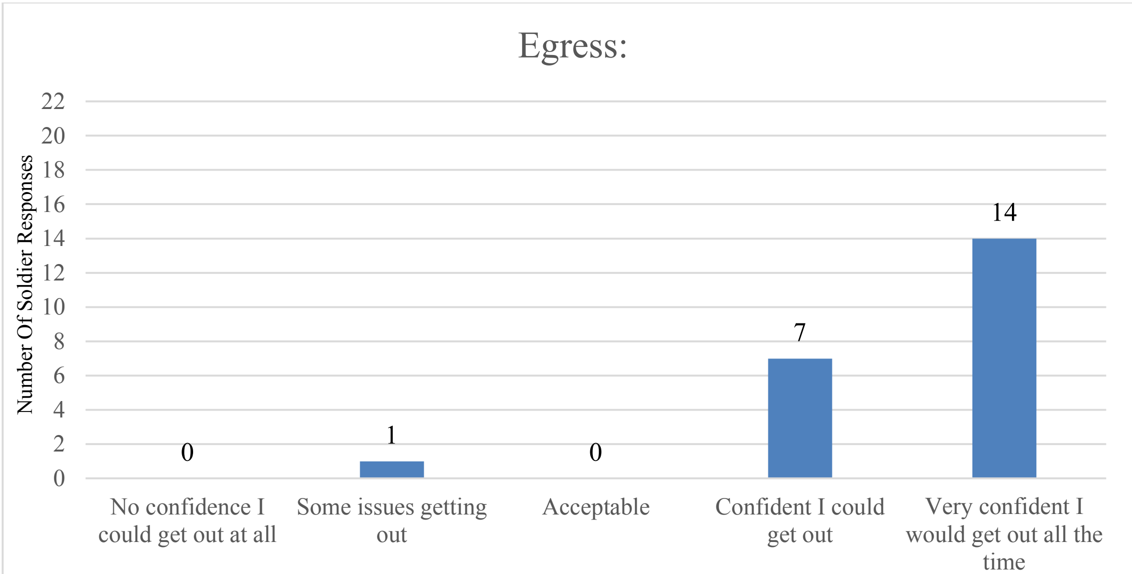

Figure 32: Secondary System Design Egress Chart

Vehicle egress was rated on a scale from 1 through 5. One (1) was the lowest rating, which would have been selected should the occupant determine that he would have no confidence of being able to doff the restraints. Five (5) was the highest rating, which would be selected should the occupant determine that he would have high confidence of being able to doff the restraints. As shown in Figure 32, 14 Soldiers concluded that they would be very confident and would be to egress the vehicle easily. Seven Soldiers concluded that they would be confident that they could easily egress the vehicle. None of the Soldiers concluded that they would be confident that they could acceptably egress the vehicle. One Soldier concluded that he had some issues egressing the vehicle and resulted in a lower confidence in the restraint system. While none of the Soldiers indicated that they would have no confidence in being able to egress the vehicle.

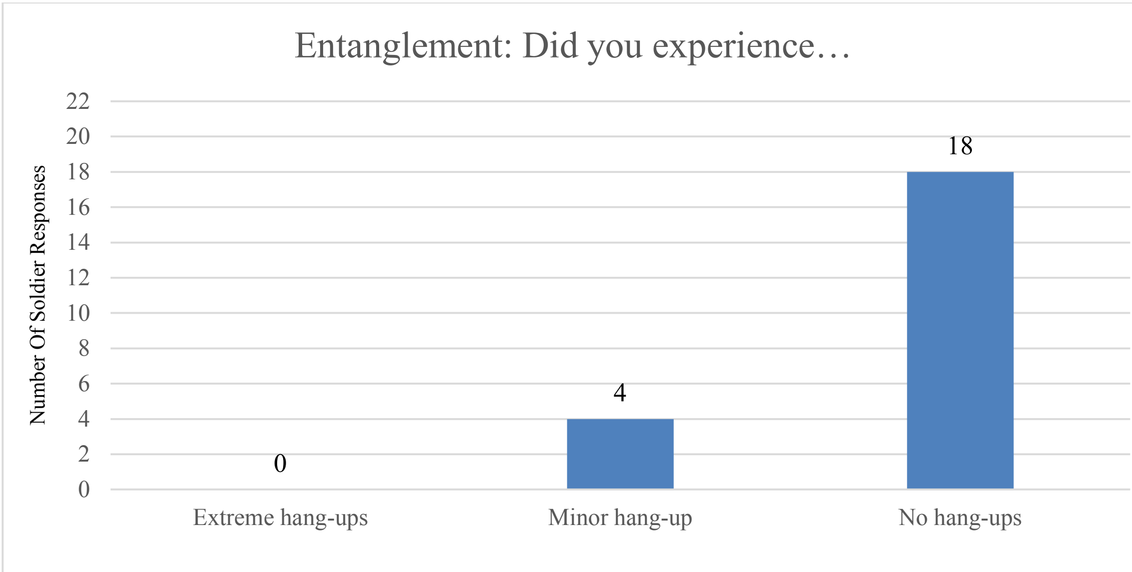

Figure 33: Secondary System Design Entanglement Chart

Restraint entanglement was rated on a scale from 1 through 3. One (1) was the lowest rating, which would demonstrate extreme hang-ups on gear. Three (3) was the highest rating, which would demonstrate no hang-ups on gear. As shown in Figure 33, 18 Soldiers experienced no hang-ups on gear. Four Soldiers concluded that they experienced minor hang-ups on gear. While none of the Soldiers experienced extreme hang-ups.

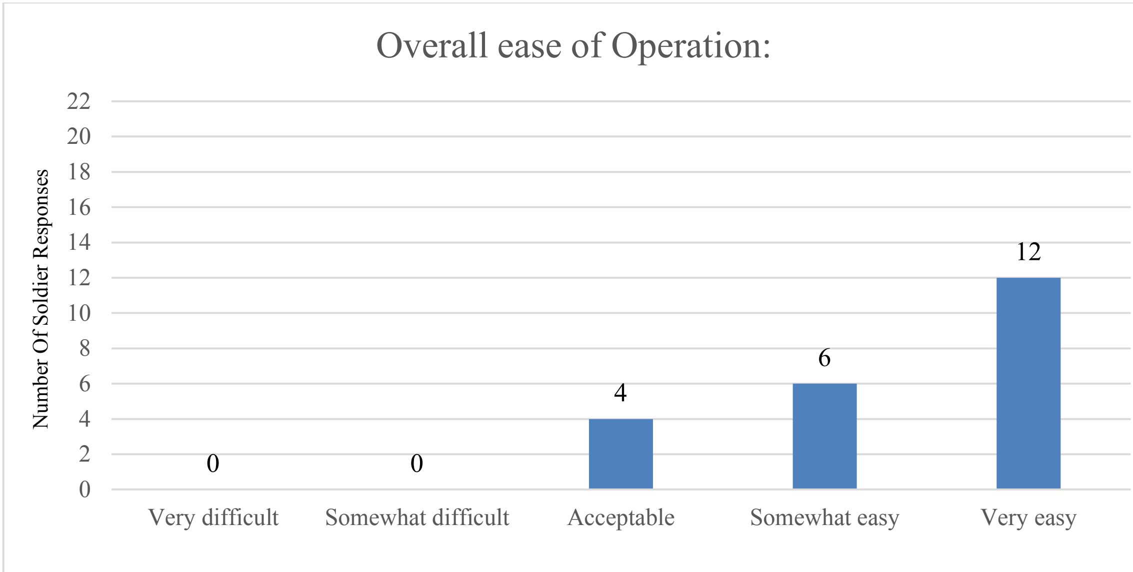

Figure 34: Secondary System Design Ease of Operation Chart

Overall ease of operation was rated on a scale from 1 through 5. One (1) was the lowest rating, which would have been selected should the occupant determine that the restraints are very difficult to operate. Five (5) was the highest rating, which would be selected should the occupant determine that the restraints are very easy to operate. As shown in Figure 34, 12 Soldiers found the restraints very easy to operate. Six Soldiers found that the restraints were somewhat easy to operate. Four Soldiers found that the restraints had an acceptable operational ease rating. None of the Soldiers found operating the restraints to be somewhat difficult or very difficult.

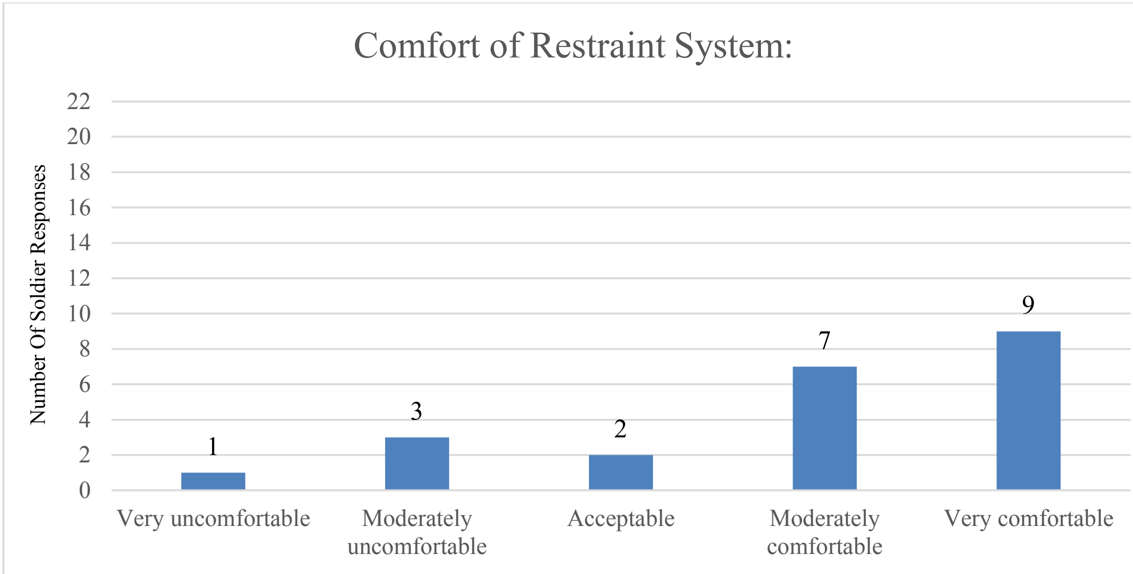

Figure 35: Secondary System Design Restraint System Comfort Chart

Overall comfort of the restraint system was rated on a scale from 1 through 5. One (1) was the lowest rating, which was considered very uncomfortable. Five (5) was the highest rating, which was considered very comfortable. As shown in Figure 35, nine Soldiers found the restraints to be very comfortable. Seven Soldiers found that the restraints to be moderately comfortable. Two Soldiers found the restraints comfort to be acceptable. Three Soldiers found the restraints to be moderately uncomfortable. One Soldier found the restraints to be very uncomfortable.

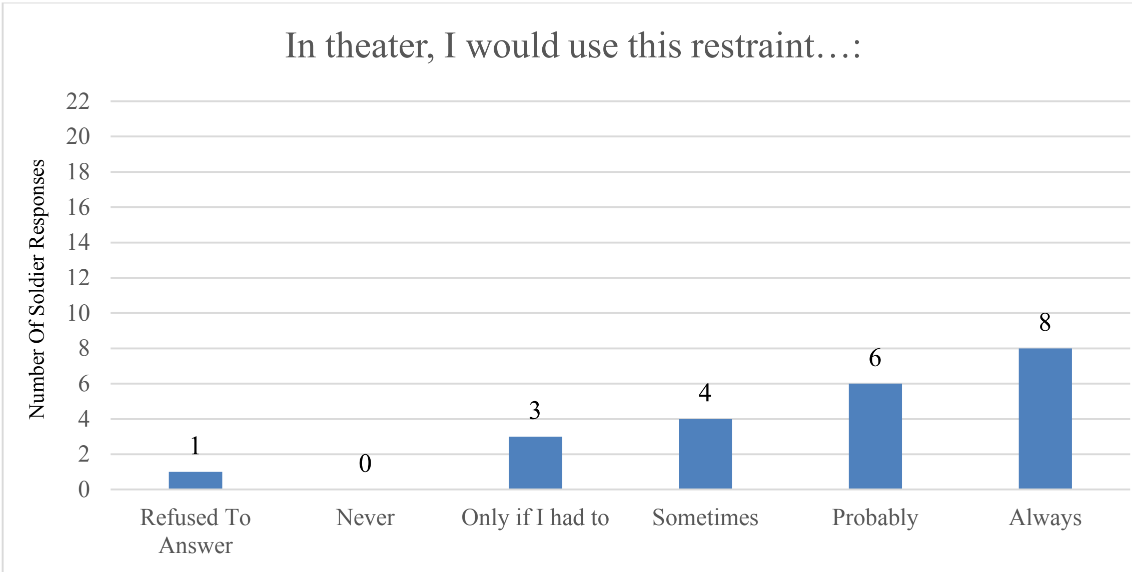

Figure 36: Secondary System Design Restraint Usage Chart
(Probability of utilizing this particular restraint design in the field)

Overall restraint system usage was rated on a scale from 1 through 5. One (1) was the lowest rating indicating the Soldier would never use this restraint. Five (5) was the highest rating indicating the Soldier would always use this restraint system. As shown in Figure 36, eight Soldiers would always wear these restraints. Six Soldiers would probably wear these restraints. Four Soldiers would sometimes wear these restraints. Three Soldiers would only wear these restraints if they had to. None of the Soldiers would ever wear these restraints. While one Soldiers refused to answer the question

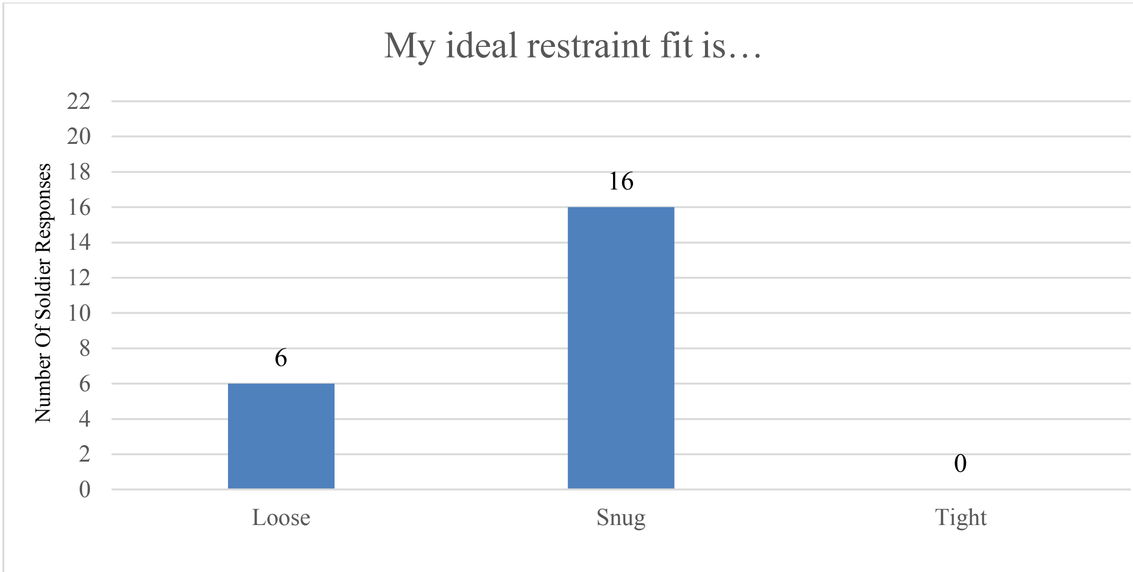

Figure 37: Overall Ideal Restraint Fit Preference Chart

The Soldiers were asked about what their ideal restraint system fit and was rated on a scale from 1 through 3. One (1) being loose, 2 being snug and 3 being tight. As shown in Figure 37, 16 Soldiers preferred when their restraint system was snug to their body. Six Soldiers preferred when their restraint system was loose on their body. None of the Soldiers preferred when their restraint system was tight to their body.

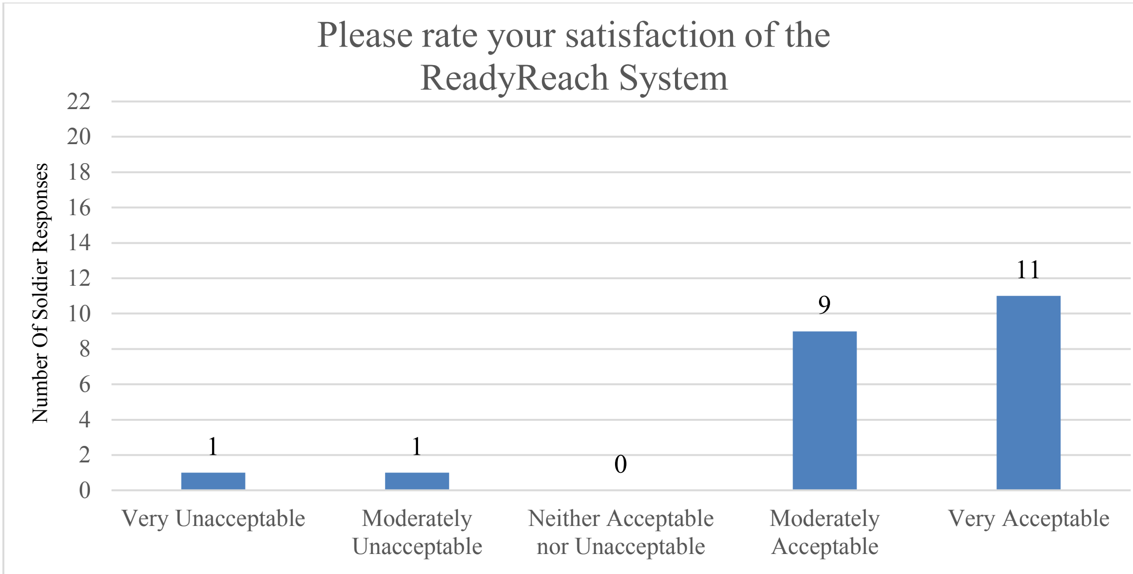

Figure 38: Secondary System ReadyReach Satisfaction Chart

Overall ReadyReach System usage was rated on a scale from 1 through 5. One (1) was the lowest rating of very unacceptable. Five (5) was the highest rating of very acceptable. As shown in Figure 38, 11 Soldiers found the ReadyReach System to be very acceptable. Nine Soldiers found the ReadyReach System to be moderately acceptable. None of the Soldiers found the ReadyReach System to be neither acceptable nor unacceptable. One Soldier found the ReadyReach System to be moderately unacceptable. One Soldiers found the ReadyReach System to be very unacceptable.

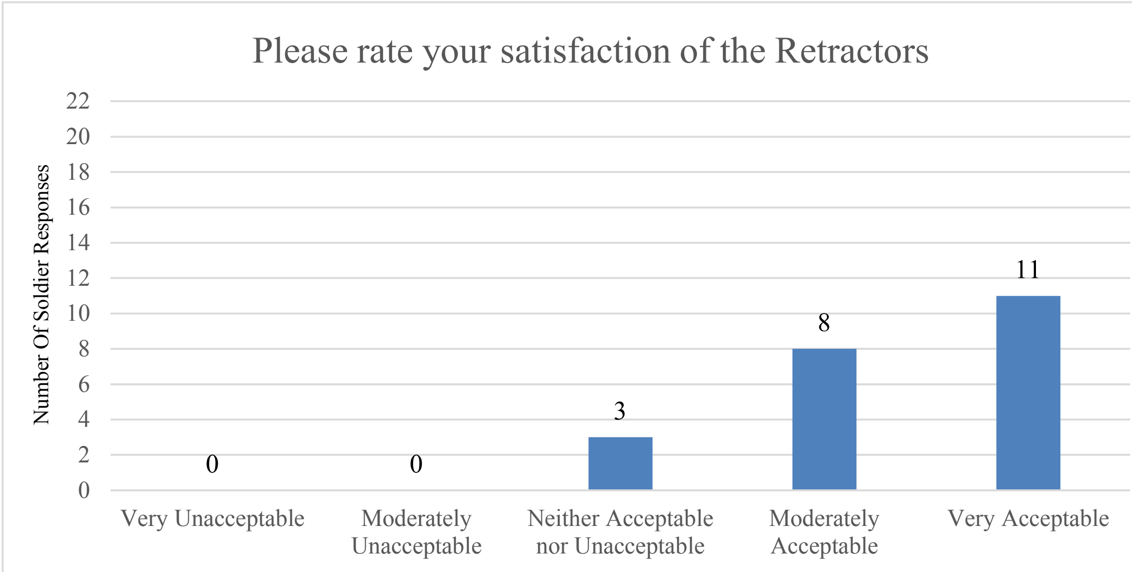

Figure 39: Overall Perception of Retractors Chart

Overall retractor satisfaction was rated on a scale from 1 through 5. One (1) was the lowest rating of very unacceptable. Five (5) was the highest rating of very acceptable. As shown in Figure 39, 11 Soldiers found the retractor satisfaction to be very acceptable. Eight Soldiers found the retractor satisfaction to be moderately acceptable. Three Soldiers found the retractor satisfaction to be neither acceptable nor unacceptable. None of the Soldiers found the retractor satisfaction to be neither moderately unacceptable nor very unacceptable.

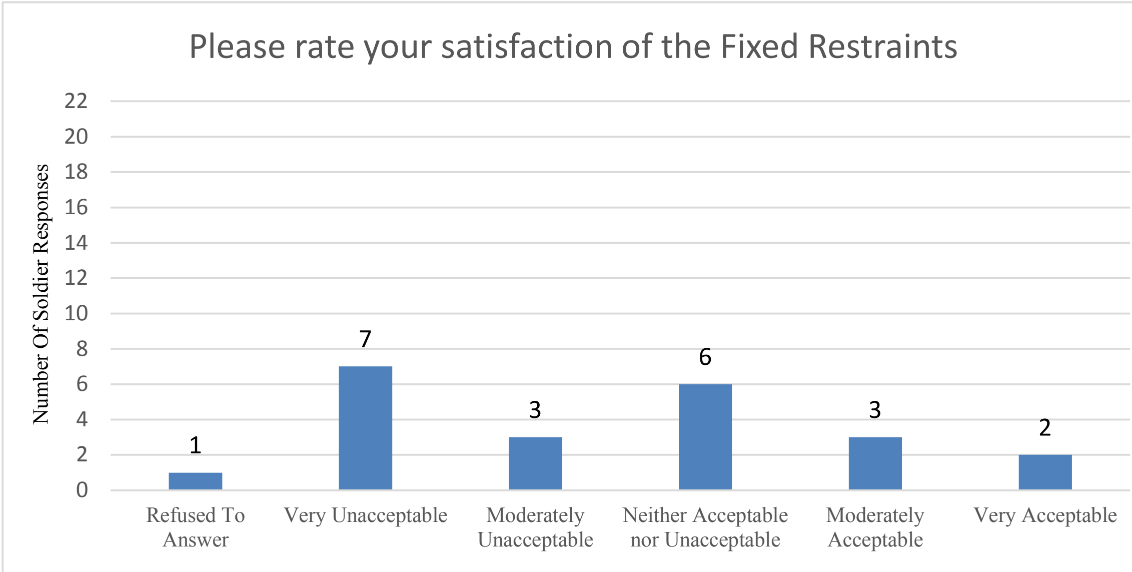

Figure 40: Overall Perception of Fixed Restraints Chart

Overall fixed restraints satisfaction was rated on a scale from 1 through 5. One (1) was the lowest rating of very unacceptable. Five (5) was the highest rating of very acceptable. As shown in Figure 40, two Soldiers found fixed restraints to be very acceptable. Three Soldiers found the fixed restraints to be moderately acceptable. Six Soldiers found the fixed restraints to be neither acceptable nor unacceptable. Three Soldiers found the fixed restraints to be moderately unacceptable. Seven Soldiers found the fixed restraints to be very unacceptable. One Soldier refused to answer the question

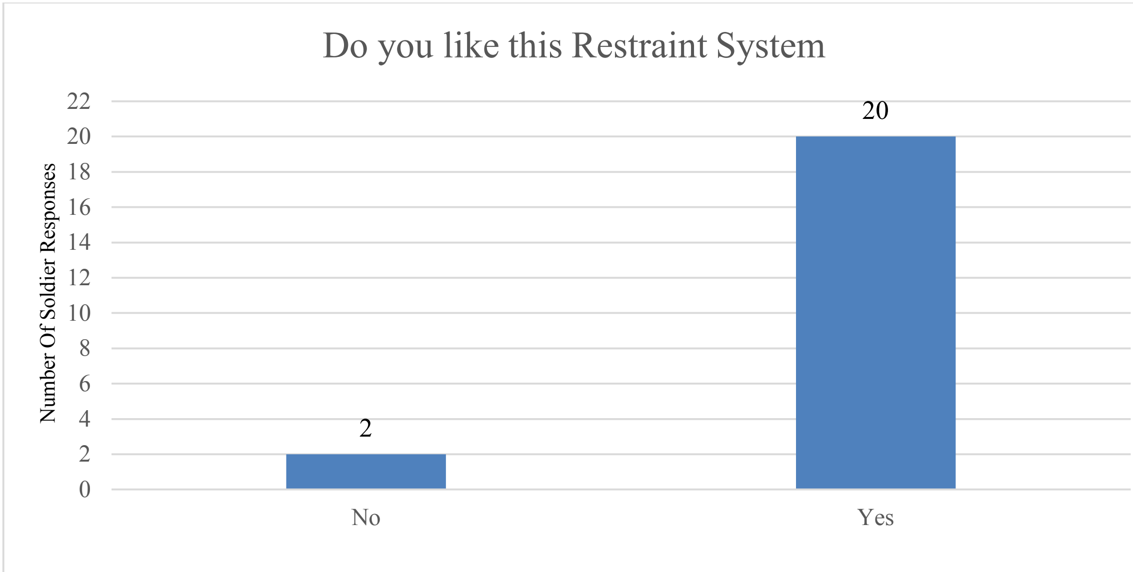

Figure 41: Secondary System Design Overall Perception of Restraints Chart

The overall ReadyReach restraint system perception was reviewed for each Soldier asking if they liked the overall system. As shown in Figure 41, 20 Soldiers liked the ReadyReach restraint system. Two Soldiers did not like the ReadyReach restraint system.

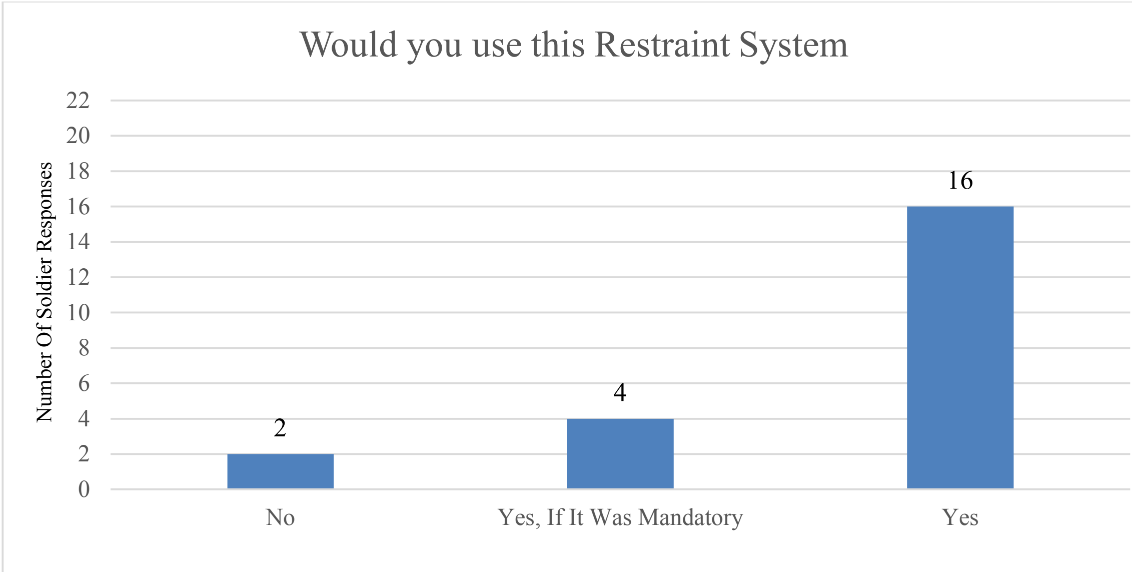

Figure 42: Secondary System Design Overall Potential Usage of Overall Design Chart

The overall ReadyReach restraint system perception was reviewed for each Soldier asking if they would use this restraint system acceptable. As shown in Figure 42, 16 Soldiers would use this restraint system. Four Soldiers would wear the restraint system if they had to / if it was mandatory. Two Soldiers would not wear the restraint system.

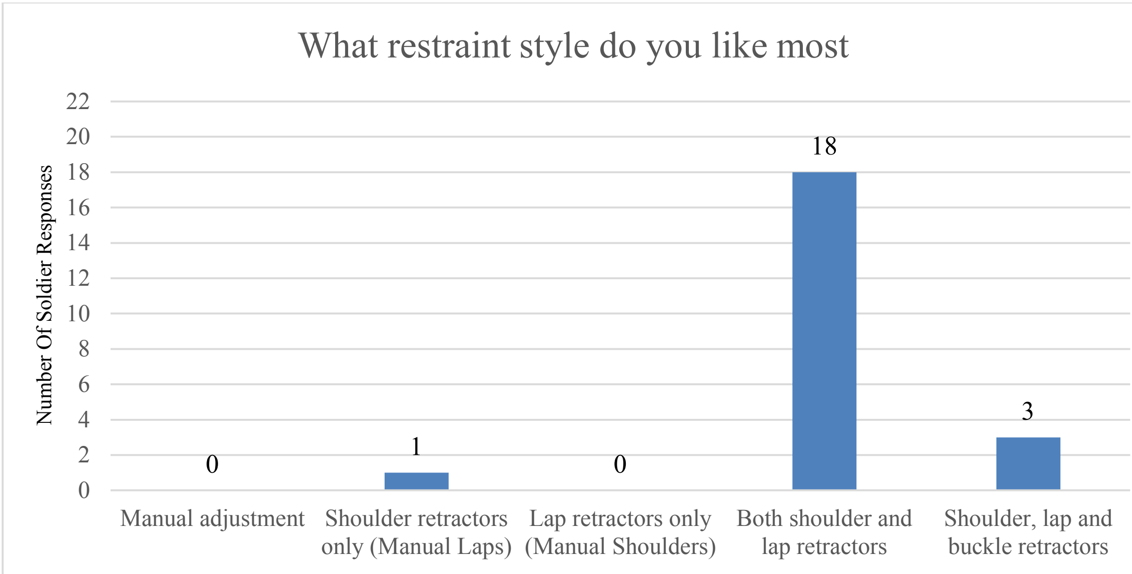

Figure 43: Percentage of Restraint Style Preference Chart

Overall restraint style preference was selected by the Soldiers. The available choices were: manual adjustment (fixed), shoulder retractors only (manual laps, fixed), lap retractors only (manual shoulders, fixed), both shoulder and lap retractors and shoulder, lap and buckle retractors. As shown in Figure 43, three Soldiers selected shoulder, lap and buckle retractors as their preferred system. Eighteen Soldiers chose both shoulder and lap retractors as their preferred system. One Soldier selected shoulder retractors only (manual laps) as their preferred system. None of the Soldiers selected lap retractors only (manual shoulders) or manual adjustment.

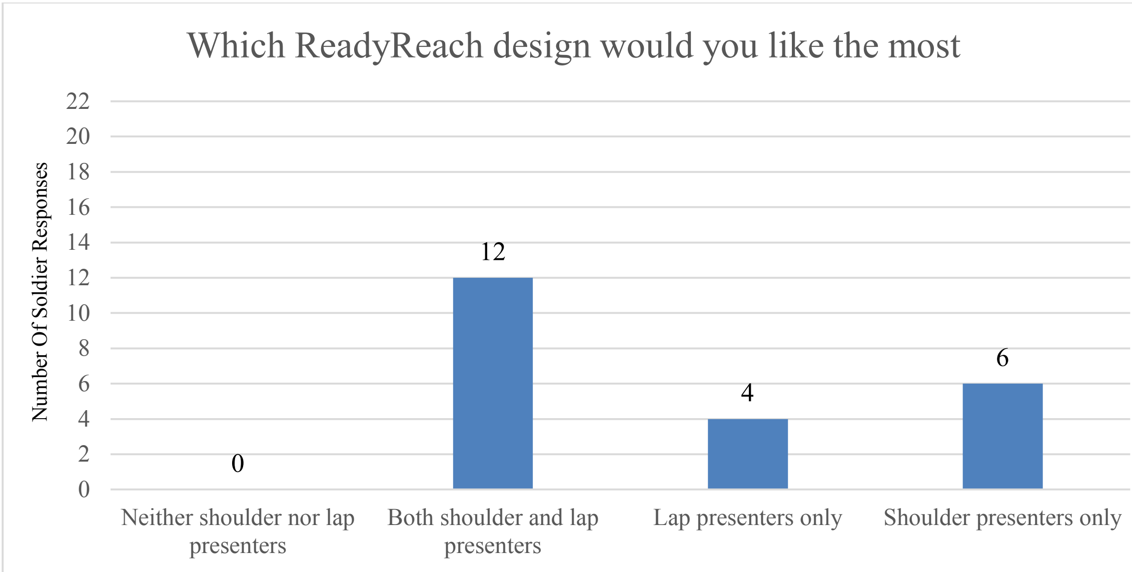

Figure 44: Secondary System Design ReadyReach Preference Chart

Overall ReadyReach location preference was selected by the Soldiers. The available choices were: shoulder presenters only, lap presenters only, both shoulders and lap presenters and neither shoulder nor lap presenters. As shown in Figure 44, six Soldiers selected shoulder presenters only as their preferred system. Four Soldiers selected lap presenters only as their preferred system. Twelve Soldiers chose both shoulders and lap presenters as their preferred system. The Soldiers did not select neither shoulder nor lap presenters as their preferred system

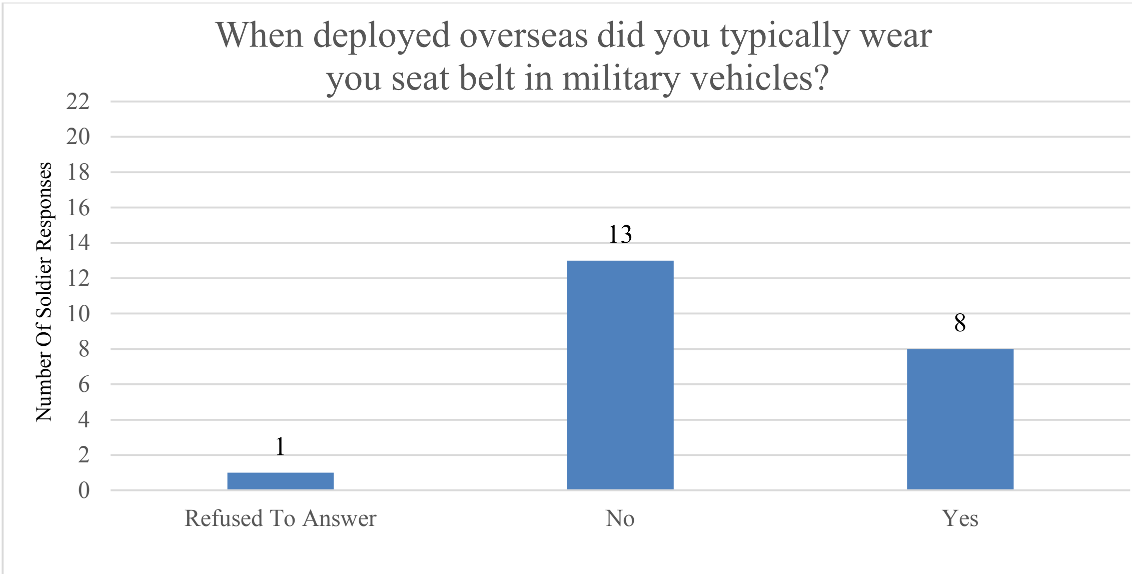

Figure 45: Percentage of Deployed Usage Chart

The Soldiers were asked if they typically wore restraints when deployed. As shown in Figure 45, eight Soldiers wore restraints when deployed. Thirteen Soldiers did not wear restraints when deployed. One Soldier refused to answer the question.

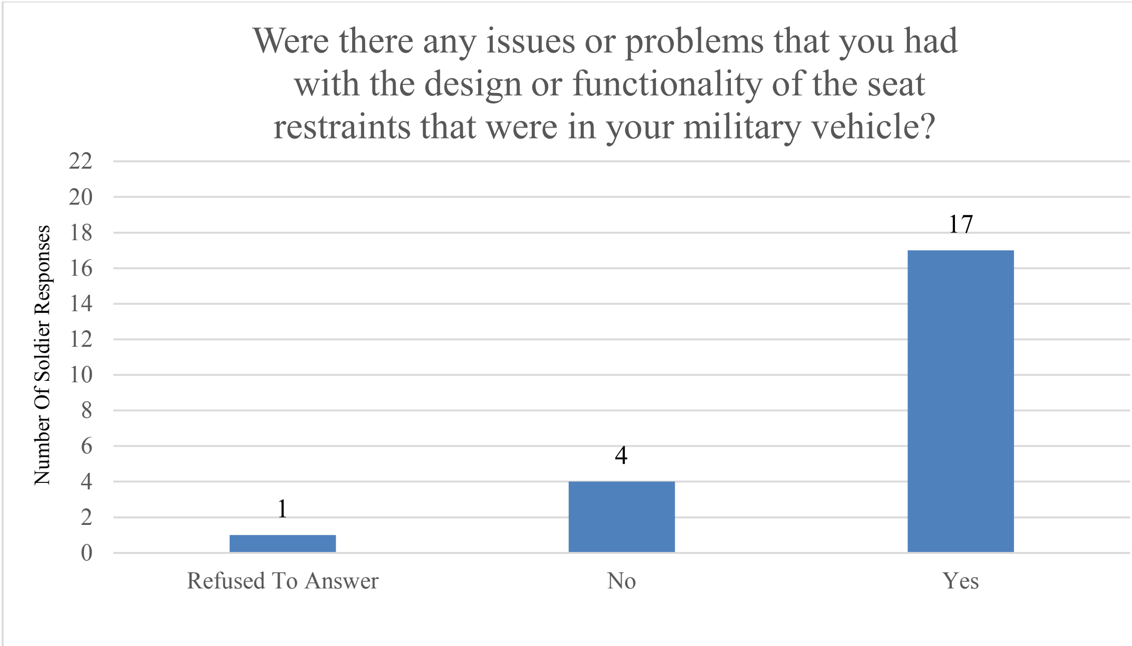

Figure 46: Percentage of in Theatre Restraint Issues Chart

The Soldiers were asked if they typically had any issues or problems with overall restraint system functionality in military vehicles. As shown in Figure 46, 17 Soldiers had problems with restraint systems found in the field. Four Soldiers did not have problems with restraint systems found in the field. One Soldier refused to answer the question.

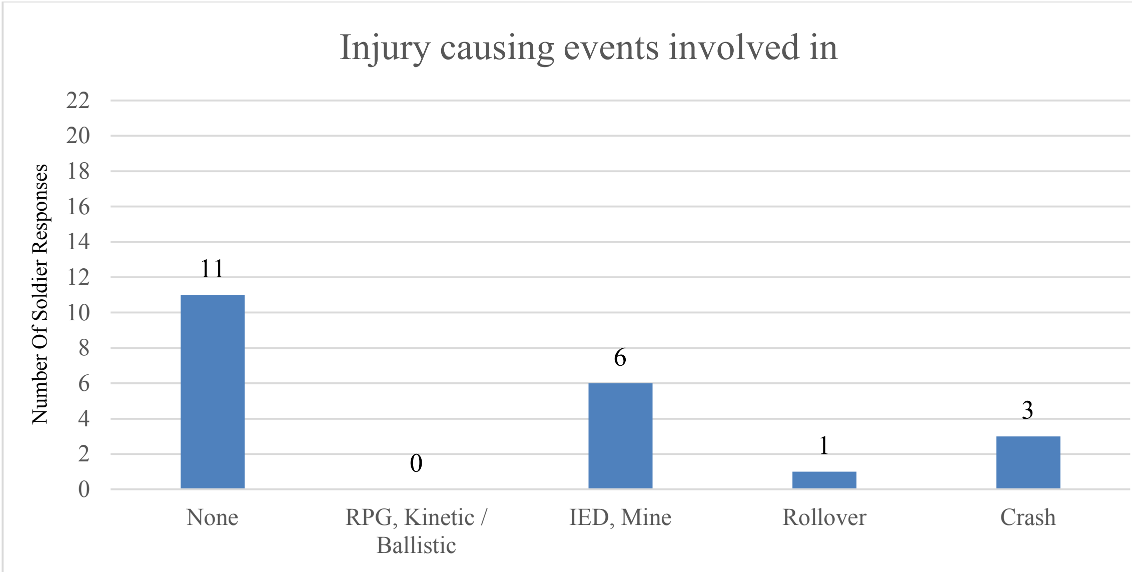

Figure 47: Percentage of Injury Causing Events in Theatre Chart

The Soldiers were asked if they were involved in any type of accident event when they were deployed. The available choices were: crash, rollover, IED-mine, RPG – kinetic/ballistic and was not involved in an event. As shown in Figure 47, three Soldiers were involved in crash events. One Soldier was involved in a Rollover event. Six Soldiers were involved in IED, mine blast events. None of the Soldiers were involved in an RPG, kinetic / ballistic events. Eleven Soldiers were not involved in any events.

Discussion

During the development of the OCP TECD program, a representative vehicle body was created for the purpose of interior system evaluations and concept visualization for Army leadership. The demonstrator provided insight and allowed Soldiers to feel what the interior of an actual vehicle would be like. The seating systems contained the ReadyReach restraints and functioned as a production intent system would. An evaluation of the demonstrator was conducted to focus on all aspects of the interior. The restraint system evaluation was conducted at this time focusing on the production intent restraint system featuring ReadyReach

Belt accessibility, buckle accessibility, egress, entanglement, ease of operation, ReadyReach satisfaction, retractor satisfaction, restraint usability, restraint acceptance (How much do you like the Restraint), potential of use (Would you use this restraint), what restraint system style do you like, and, which style of ReadyReach you prefer all received ratings of at least 50% in favor of the designed system. The ratings, which scored less than 50% were comfort and usability of restraint (In theatre I would use this restraint). Comfort indicators proved positive, considering that 41% of Soldiers considered the system very comfortable and 32% moderately comfortable, which in total were higher than the lowest three ratings of very uncomfortable (4%), moderately uncomfortable (14%), and Acceptable (9%). For the question, in theatre I would use this restraint, 38% of Soldiers would always wear this restraint while 29% probably would in total were higher than the lowest ratings of sometimes (19%), only if I had to (14%) and never (0%).

Conclusion

The restraint systems containing the ReadyReach presenters on both the shoulder and lap restraints were the most preferred system by most of the Soldiers. The Soldiers noted that ingress was made easier by this design and the restraints were readily accessible once seated. In the restraint systems without presenters, the restraints were difficult to access (for both manually and automatically retracting belts). Based on the evaluations, it was clear that the Soldiers preferred and felt more comfortable with the ReadyReach presenters vs. the sleeved presenters, so it was recommended that ReadyReach presenters on both the shoulder and the lap restraints be considered for future designs.

Overall the Soldier response was positive towards the designed ReadyReach system. The OCP TECD demonstrator was also well received by Army leadership, Contractors and other Army divisions within the research and development community. The system was therefore tested and certified on the actual OCP TECD platform. Today the restraint system is available for use on any military or commercial application vehicle.

Chapter 3

Optimal Restraint System Routing Procedures for Restraint System Development[2]

Abstract

A process for donning restraints did not exist as related to Soldier gear encumbrance. For laboratory testing, restraint donning was left to the discretion of the technician or test engineer setting up the ATD and resulted in increased occupant excursion. Therefore the GSS BMT, United States TARDEC, Warren, MI. conducted research, which was accomplished through restraint system testing. This testing consisted of both Blast and Crash test modes. It was discovered that the ideal testing method couples the occupant to the seat and reduces the amount of restraint to gear interaction. When properly donned the occupant experiences reduced amounts of excursion vs. the improperly restrained occupant. This resulted in a procedure for which restraint systems are to be donned for test events. The routing procedure is included in this publication.

Introduction

The United States Army employs various types of vehicles to perform tactical, logistical, and peacekeeping related operations. Vehicle sizes and weights range accordingly as required by the mission. Each of these vehicles is susceptible to Blast, Crash, Rollover, and other injury causing events. As such, the mission of the GSS BMT is to counteract these events and help protect the Soldiers as they perform their required mission.

The performance of the stated military vehicles when subjected to Blast, Crash, Rollover, and other injury causing events can vary depending on vehicle size, weight,

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[2] "Karwaczynski, S., "Optimal Restraint System Routing Procedures for Restraint System Development", Proceedings of the 2015 GVSETS & APBI, (2015)"

crush/energy absorbing structures and devices in addition to the under body shape and/or kit installed on the vehicle. In conjunction with these systems, a restraint system acts as a coupling mechanism to the energy-absorbing seat. Ideally, the amount of relative motion the occupant has to the seat is limited to prevent contact to surrounding surfaces.

As Soldiers perform their missions, they find themselves in vehicles that are not comfortable and do not allow much space for movement. Surfaces in these vehicles are hard and rarely (if ever) contain energy-absorbing surfaces that would allow the energy to be absorbed in case of an event. Therefore, it is critical for the Soldiers to don their restraint system properly at all times, regardless of comfort and/or annoyance.

When the design for a restraint system for military applications is approached, Soldier Gear (Encumbrance), Vehicle Interior Dimensional Limitations (Either Legacy or New Platform) and Future Retrofits/Upgrades (Equipment and/or Entire Platform) must be considered. Failing to take these considerations into account could result in the restraint system not being utilized or completely removed or cut out of the vehicle.

TARDEC GSS, Warren, MI had designed an optimized restraint system for the Soldier. However, during blast and sled testing, improper donning was found to increase occupant excursion increasing the potential of contacting interior surfaces. When evaluated, excessive excursion caused gear damage and increased restraint loading. Therefore, a proper routing procedure was created and evaluated.

Methodology

The restraint system was evaluated in various testing scenarios namely Crash[7], Drop Tower, and Blast testing. Initially no particular methodology was employed for donning the restraints other than ensuring that the restraints were over the gear and "tight" as per the test technicians' and test engineers' judgment. Any manually adjusted segments of the restraints were cinched as tight as possible, with the technicians using both hands and pulling until the restraints were as taut as possible. This type of donning would not represent what is seen in the field; the likeliness of having a Soldier don restraints for another Soldier is low (but possible in certain situations). An occupant donning a restraint has limited ability to pull restraints on himself while seated as tight as a technician at a testing facility who uses his entire body mass to tighten the restraint on an ATD.

Sled Testing

During the development cycle of the restraint system for OCP TECD, sled testing was conducted as the first step[7]. The frontal crash sled test series used for this effort utilized a rigid seat mounted on a servo-hydraulic sled. The sled was propelled by an open-loop pneumatic actuator and the acceleration profile was controlled by a closed-loop 10 kHz hydraulic servo-brake A fix rigid steel seat intended for ECE R16 certification testing was modified to accept a 5th point, to replicate the intended seat design angle and to replicate the mounting of the remainder of the restraints in the intended design locations[7]. The test matrix for the series is represented in Table 14.

Table 14: Sled Series Test Matrix

Run Number	RUN 003	RUN 004	RUN 005	RUN 006	RUN 007
Torso Restraint	OFF HIGHWAY ELR (2)	OFF HIGHWAY ELR (2)	FMVSS 209 ELR (2)	FMVSS 209 ELR (2)	FMVSS 209 ADDITIONAL WEB LENGTH ELR (2)
Pelvis Restraint	FIXED (2)	FIXED (2)	MANUAL ADJUST (2)	MANUAL ADJUST (2)	IMMI MACR REDUCED WEB LENGTH ALR (2)
Crotch	Fixed	Fixed	Fixed	Fixed	Fixed
Foot Rest	High 8"	High 8"	High 8"	Low 3"	Low 3"

The pulse utilized for this series was derived from internal U.S. Army modeling and simulation studies, historical crash data conducted prior to the inception of this project and the comparison of FMVSS and other readily available crash pulses. Due to the rigidity of military vehicles and lack of frontal deformation, higher G forces were created and were taken into account with the development of this pulse. The final developed pulse for the OCP TECD program is captured in Figure 48.

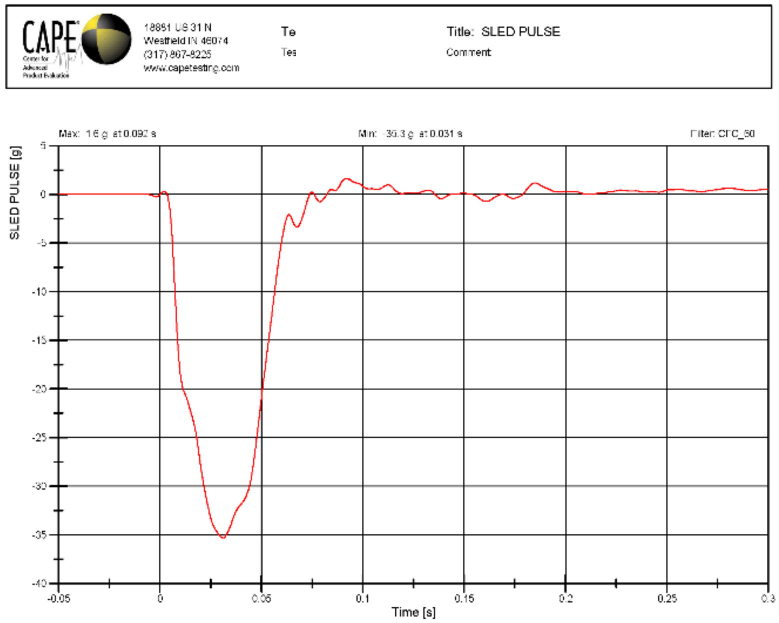

Figure 48: TARDEC DEVELOPED OCP TECD PULSE

Initial Restraint Routing

As shown by Figure 49 and Figure 50 the lap restraints were routed over the packs and the restraint load cells were placed in a manner where the gear was in contact with them prior to test. Figure 51 illustrates the shoulder webbing passing over gear. In this particular gear set configuration, the restraints were uniformly placed on the occupant.

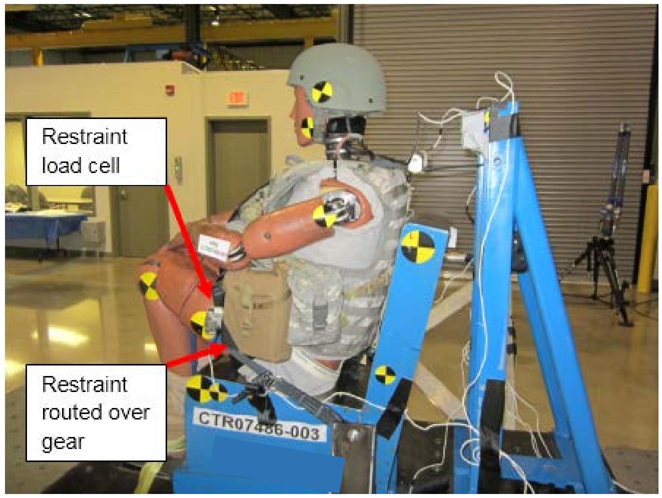

Figure 49: Left View of ATD On Sled Pre-Test

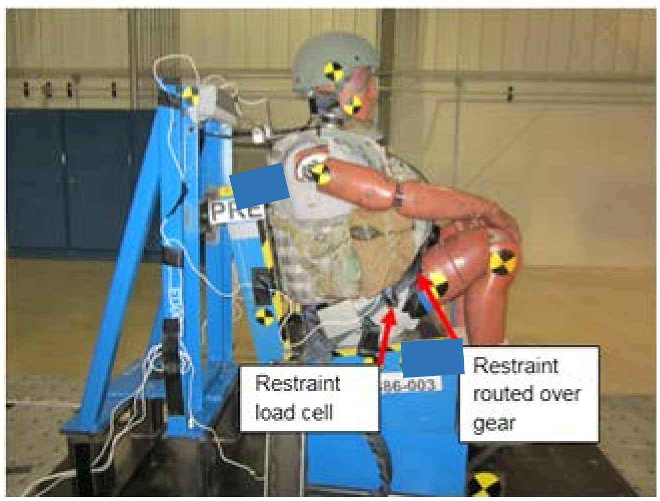

Figure 50: Right View Of ATD On Sled Pre-Test

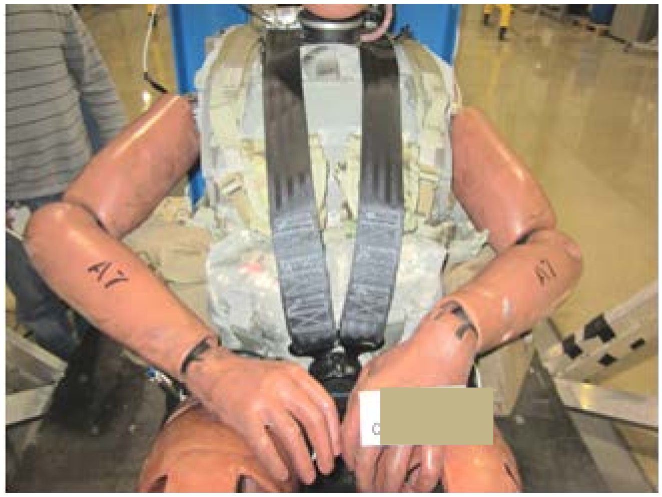

Figure 51: Frontal View Of ATD On Sled Pre-Test

Occupant Displacement Measurement

During sled testing, measurements were taken at the knee during the ATD's maximum excursion via video analysis. The video was analyzed millisecond by millisecond to determine the maximum excursion before the ATD changed direction. Targets located on the head and knee where utilized to obtain this measurement.

Crew Seating Blast Effects Simulator (CSBES)

During blast confirmation testing, an anomaly was discovered. The ATD had travelled upwards towards where the vehicle ceiling location would be located. The particular test asset did not contain a roof, but if it had, the potential for contact with the head would be very likely. This prompted testing to be conducted on the CSBES at ARL in Adelphi, Maryland. The purpose of the testing was to identify the excursion the occupant encountered in the blast seat when subjected to the blast pulse in an ideal restraint routing condition and in a condition mimicking the blast test restraint routing. The test matrix for the series is represented in Table 15. While five tests were conducted, only Runs 001 and 003 were used in this analysis. Runs 002, 004, and 005 were not related to this program and were not analyzed in this report.

Table 15: Sled Series Test Matrix:

Run Number	RUN 001	RUN 002	RUN 003	RUN 004	RUN 005
Torso Restraint	OFF HIGHWAY ELR (2)	OFF HIGHWAY ELR (2)	OFF HIGHWAY ELR (2)	OFF HIGHWAY ELR (2)	Fixed
Pelvis Restraint	MACR ALR (2)	MACR ALR (2)	MACR ALR (2)	MACR ALR (2)	Fixed
Crotch	Fixed	Fixed	Fixed	Fixed	Fixed

The accelerative pulse utilized for this series closely mimicked the actual blast test. Due to the sensitivity of this data, a graph depicting this pulse has been omitted

Blast Test Restraint Placement

As shown by Figure 52 through Figure 55 the restraints were purposefully routed incorrectly to mimic the test setup during the blast test. The lap restraints were routed over the packs where the gear was in contact with them prior to test and the left hip retractor was rotated forward to replicate the blast test setup condition. In addition, a test was run with proper placement of restraints to compare the effect that it had on the restraint load cell results.

Figure 52: Rear Right Oblique View of ATD with Misplaced Restraints

Figure 53: Front Right Oblique View of ATD with Misplaced Restraints

Figure 54: Front Left Oblique View of ATD with Misplaced Restraints

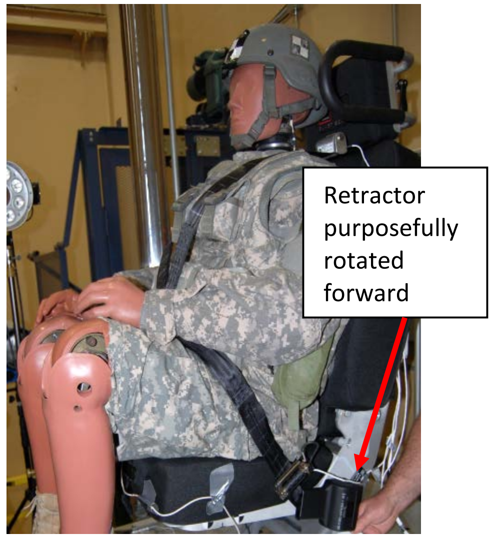

Figure 55: Left View of ATD with Misplaced Restraints

Occupant Displacement Measurement

During sled testing, measurements were taken at the knee during the ATD's maximum excursion via video analysis. The video was analyzed millisecond by millisecond to determine the maximum excursion before the ATD changed direction. The target was located on the cheek and was utilized to obtain this measurement.

Testing Results

Sled Testing

Results indicate that improperly routed restraints contributed to increased excursions as is depicted in Figure 56. Measurements were taken at the knee during the maximum excursion via video analysis from both tests. The improperly routed restraints contributed to increased maximum pelvic excursion. The maximum pelvic excursion of the dummy with the improperly routed restraint was 80mm greater than the properly routed restraints as seen in Figure 56.

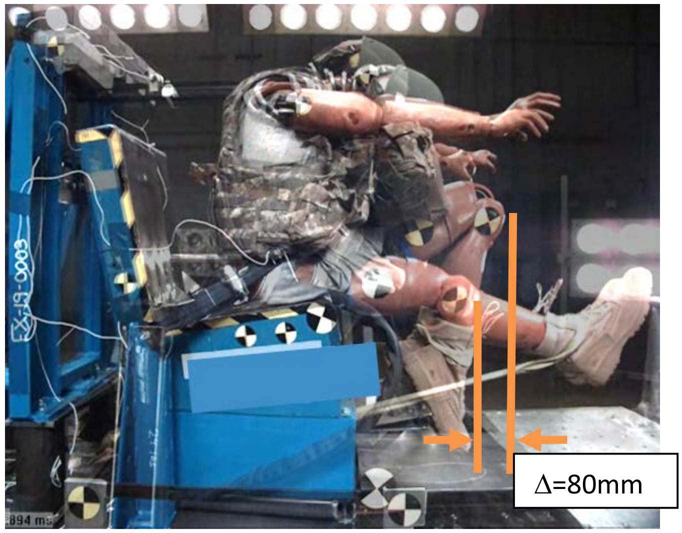

Figure 56: Maximum ATD Pelvic Excursion Properly vs. Improperly Routed Restraints

The lap restraints slipped under the packs, causing a drop in load on the lap restraints. Figure 57 and Figure 58 highlight the drop in load (loss of restraint). The rise in the load cell data occurs once the restraints have worked their way under the gear set and begin loading the ATD once again.

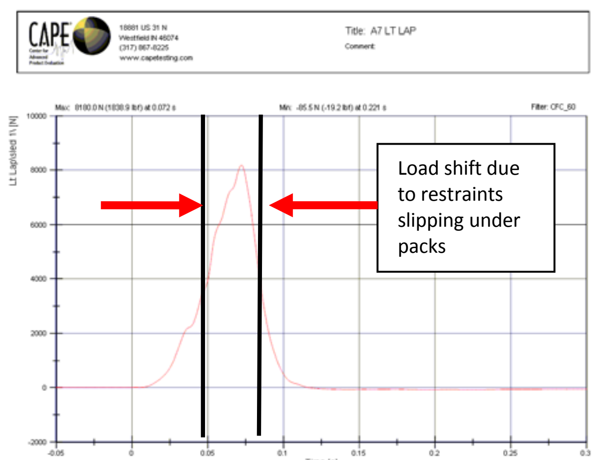

Figure 57: Left Lap Load Cell Data

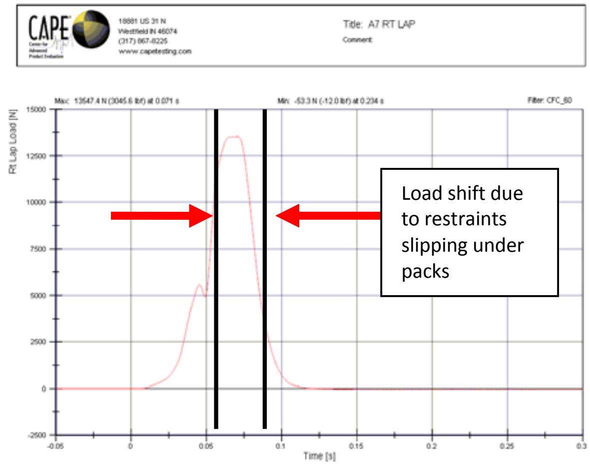

Figure 58: Right Lap Load Cell Data

Crew Seating Blast Effects Simulator (CSBES)

Results indicated that the improperly routed restraints contributed to increased excursions as depicted in Figure 59. Measurements were taken at the cheek during the maximum excursion via video analysis from both tests. The improperly routed restraints contributed to increased head excursion. The maximum head excursion of the dummy with the improperly routed restraint was 113mm greater than the properly routed restraints as seen in Figure 59.

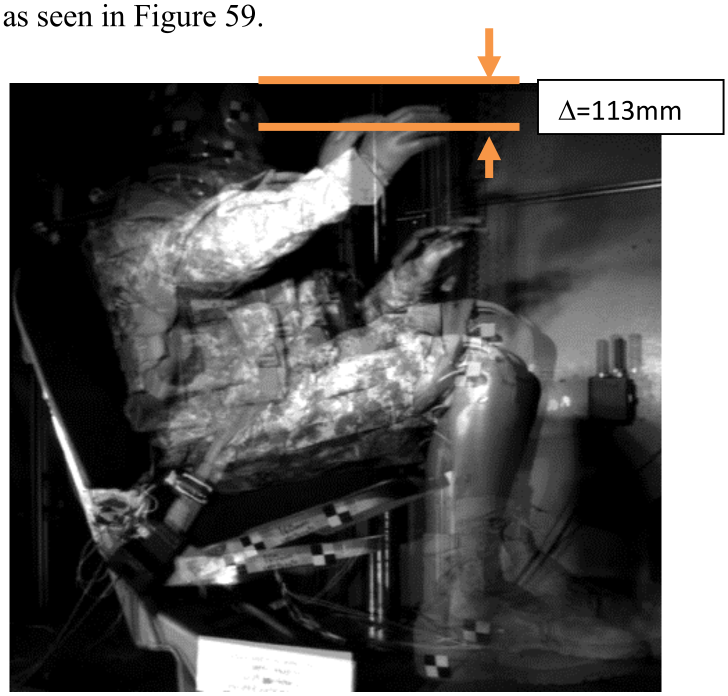

Figure 59: Maximum ATD Pelvic Excursion Properly vs. Improperly Routed Restraints

The load on the lap caused a drop in load in the restraints as illustrated in Figure 60 and Figure 61. The properly routed restraint provided a sustained load during the blast event for both the left and right lap restraints. A loss of restraint occurred for improperly routed restraints, with the load dropping off as the restraints slipped under the pouches. The load rises once again when restraints were no longer slipping

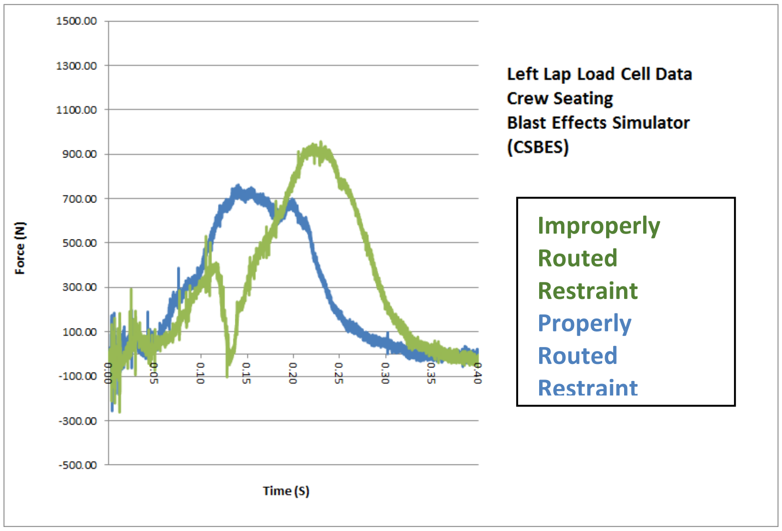

Figure 60: Left Lap Loads During Blast Simulation Test

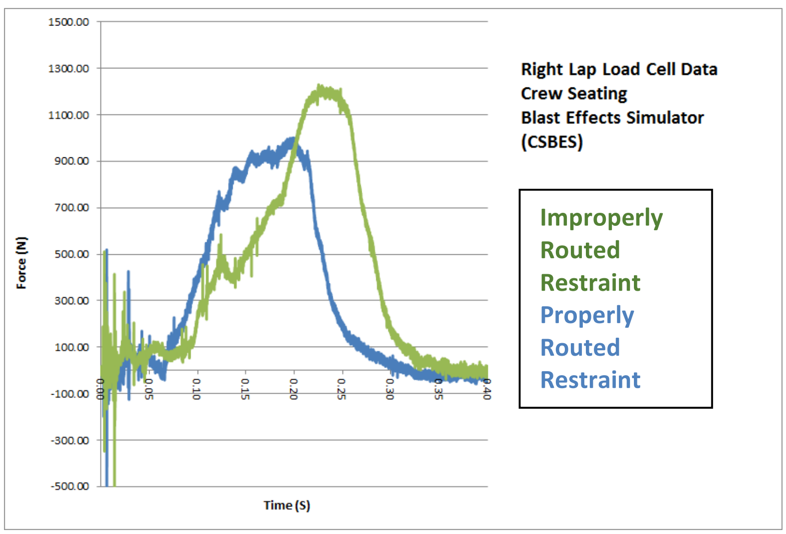

Figure 61: Right Lap Loads During Blast Simulation Test

Discussion

Sled Testing

When the restraint is routed over the encumbrance, it will continue to load and provide restraint. When the webbing finds the path of least resistance, it then slips under the pouches. During this time, the load drops until it is able to load up against the abdomen again. Once the abdomen is being loaded again, the load begins to rise. This loading can result in higher occupant injury values and further excursion.

Crew Seating Blast Effects Simulator (CSBES)

During the test, the lap restraints slipped under the packs and the left hip retractor rotating upwards, causing excessive excursion. As with the sled testing, the webbing finds the path of least resistance. During this time, the load drops until it is able to load up against the thighs. In the case of this test series, the left lap load has a sharper drop in load as the retractor rotates upwards. The properly routed restraints did not produce a drop in load, instead the load was distributed over a longer time period. This allowed for a sustained loading profile.

Conclusion

When the restraint system was evaluated in Crash and Blast testing, the restraints were initially placed as they have been in previous test series. No particular methodology was employed other than ensuring that restraints were over the gear and "tight" as per the test technicians and test engineers judgment.

Throughout the study, placing the restraint system in a manner that is described in Appendix H is critical. The procedure covers both manual adjust restraint systems and restraint systems that contain retractors.

Chapter 4

The Effects of Soldier Gear Encumbrance on Restraints in a Frontal Crash Environment[3]

Abstract

Crash testing and validation of military vehicles has not, to date, accounted for the Soldier gear burden. Actual loads imparted onto the occupant in a representative military vehicle environment have been limited and do not reflect what an occupant would actually see in this type of an event. The U.S. Army Soldier encumbered with his gear poses a challenge in restraint system design that is not typical in the automotive world. The weight of the gear encumbrance may have a substantial effect on how the restraint system performs and protects the occupant during a frontal event. Other system level complications to military vehicle interiors are secondary impact surfaces, such as IPs, ammunition cans, and weaponry, which provide a path for off-loading the energy generated by the occupant and gear combination. The energy absorption of these surfaces, however, is not ideal in current military vehicle designs and may result in injury or death.

The goal of this study was to investigate gear and accelerative pulses as they relate to the restraints and occupant interaction. To limit experimental variation, a fixed steel seat structure was utilized throughout the entire testing series. It was hypothesized that determining these effects can lead to a restraint system design that can be optimized to provide restraint for the whole range of occupant sizes and gear variations. Further reductions in occupant injury were achieved by properly tuning the surrounding trim, air bags, and cargo contact surfaces.

Results of this study indicated the inclusion of the Soldier gear could increase the likelihood of occupant excursion and injury. Additionally lower accelerative pulses

[3] "Karwaczynski, S., Hoover, R., Jessup, C., and Paulson, K., "The Effects of Soldier Gear Encumbrance on Restraints in a Frontal Crash Environment", Proceedings of the ASME 2015 International Design Engineering Technical Conferences"

resulted in lower injury values and occupant displacements.

Introduction

When an automotive OEM develops a vehicle, the responsibility of testing and certification is defined by federal certification requirements, such as in FMVSS 208. Certification testing uses procedures, equipment, and most importantly ATDs. ATDs used for automotive safety certification in frontal crash are specifically designed, calibrated, and clothed to perform their critical tasks. The clothing these ATDs wear is minimal and simplistic when compared to Soldier clothing and gear. Automotive ATD clothing contributes only to a fraction of automotive vehicle safety performance. The study discussed in this report indicated how this clothing might be an integral part of a complex equation of factors that contribute to increased ATD loads during front crash events. The U.S. Army TARDEC GSS group was tasked with the development of a restraint system that considers PPE and higher front crash loads unique to military vehicles. The U.S. Army Soldier, encumbered with his gear, poses a challenge in restraint system validation that is not typical in the automotive world[8]. This study indicated the weight of the gear encumbrance could have an increased effect on how the restraint system performs and protects the occupant during a frontal event in a military vehicle.

A crash pulse is the vehicle deceleration experienced during a crash event. Figure 62 depicts the differences between a typical automotive (FMVSS 208) frontal crash pulse and the frontal crash pulse developed by TARDEC GSS for purposes of the study. The y-axis of the graph shows the level of acceleration measured in terms of 'g' and the x-axis of the graph is in units of time in seconds (s).

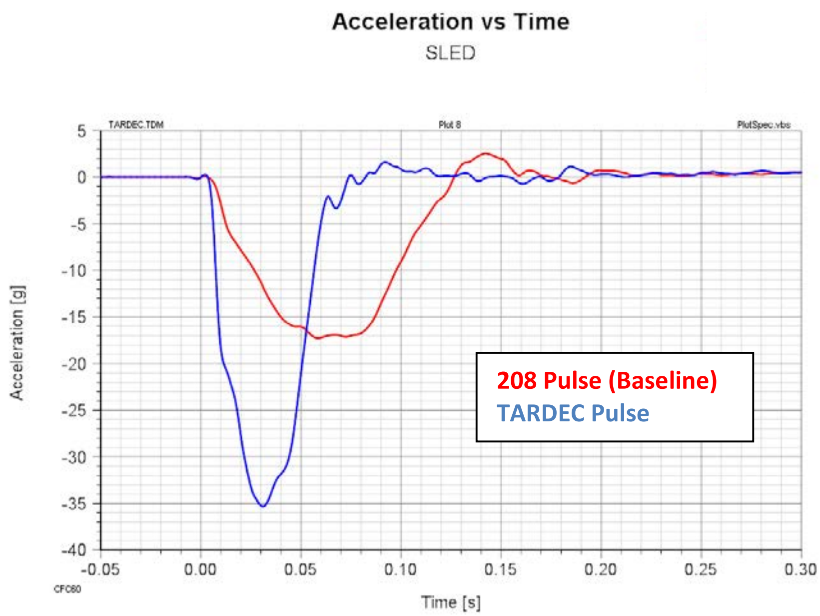

Figure 62: TARDEC DEVELOPED OCP TECD PULSE

The pulse created by TARDEC GSS for this study is more severe than those found in FMVSS, namely FMVSS 208 (Section 13, Alternative unbelted test) or FMVSS 213. FMVSS 208 only considers vehicles under 10,000lbs GVWR [1] and does not apply to vehicles with a higher weight. In addition, FMVSS 208 is intended for vehicles that have energy absorbing features and tuned safety systems for these particular features. A more severe load is deemed appropriate to represent the higher accelerations that may typically be encountered during a military vehicle front crash event that is designed with little or no energy absorbing features. When compared to the 208 pulse, the peak acceleration of the TARDEC pulse was up to 20gs higher and spread over a shorter duration as seen in Figure 62. Initial tests utilizing this pulse and an encumbered ATD resulted in restraint system failures. To find the root cause of the restraint failures, TARDEC evaluated the FMVSS 208 pulse occupant excursions, in, which various injury numbers and restraint failure rates were reduced. TARDEC GSS noted observations in automotive design, secondary impact surfaces such as knee bolsters, air bags, and glove boxes were utilized to assist in reducing injury numbers. These design features could allow the occupant to ride down the crash pulse as inherent energy absorbers.

Investigation of various occupant gear and accelerative pulse combinations can provide a better understanding of military specific restraint system performance. This can lead to a restraint system design that can be optimized for a whole range of occupant sizes and gear variations.

Test Methodology

Test Setup

Frontal decelerations present a unique challenge to an occupant restraint system when compared to that of blast or rollover conditions. Although blast and rollover events are violent and traumatic, blast events may be managed more effectively through a seat energy absorbing system rather than a restraint system. Rollover injury mitigation may be managed more effectively through energy attenuating technologies, such as the use of air bags or energy attenuating materials that are beyond the scope of this effort. It was anticipated that the added encumbrance to the existing 50th percentile ATD in a frontal crash event would produce higher injury values and potentially push the restraint components beyond the original design intended for the automotive market. Designing a restraint to work effectively for this gear load could provide adequate restraint for other, less cumbersome, less massive gear loads.

The frontal sled test series used for this effort utilized a rigid seat mounted on a servo-hydraulic sled. The sled was propelled by an open-loop pneumatic actuator and the acceleration profile was controlled by a closed-loop 10 kHz hydraulic servo-brake. Figure 63 illustrates the principle of the sled and Figure 64 shows the actual sled utilized for testing.

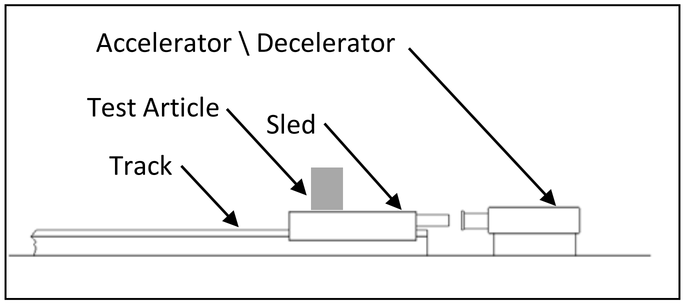

Figure 63: Crash Sled

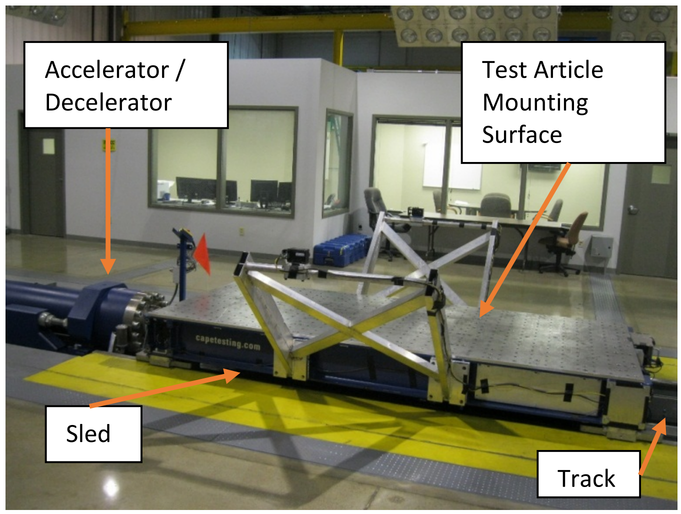

Figure 64: Servo-Hydraulic Sled

A modified rigid steel seat similar to the type used for ECE R16 compliance testing was used in this study to reduce test related experimental variation that may occur when using a conventional blast test seat. Two restraint systems were used for testing purposes. The restraints used for this study included a 5-point occupant restraint with "ReadyReach." Figure 65 depicts a typical military style 5-Point restraint system, which was designed to distribute the restraint load across the occupant's torso and limits occupant movement through an additional restraint located between the occupant's legs that typically is anchored to the seat bottom. Features of the FMVSS 209 and 302 compliant 5-Point restraint include:

1. Dual retractable shoulder restraint straps with dual severe duty emergency locking retractors (ELRs)

2. Dual retractable lap restraint straps (ALRs) with dual automatic locking retractors

3. Anti-submarining 5th point restraint strap with magnesium rotary buckle and rapid release lever, manual pull-tab style adjuster

4. Black polyester webbing with 6,000 lbs. minimum breaking strength

Figure 65: 5-Point Restraint

Figure 66 depicts the ReadyReach restraint system that presents the shoulder belts and lap belts outward, making them easier to reach for the occupant. Figure 67 depicts the test set-up for the shoulder restraint system that restrains the occupant mainly with contact to the front torso at the point of the shoulders when mounted on the rigid seat.

Figure 66: ReadyReach Restraint System

Modifications to the sled test set-up included reinforcements to accommodate additional restraint anchorages required for a 5-Point harness restraint system. The seat back angle was set to 10° from vertical and seat pan angle was set to 10° from horizontal, and remained fixed throughout the test series. The H-Point (Hip location) was set to (X=195.7mm, Y=-86.6mm and Z=-384.5mm) with the origin point being set to (0,0,0) and located on the sled.

The restraint system was anchored to structures that were fixed to the sled as shown in Figure 67, Figure 68, and Figure 69. Furthermore, all anchor points and areas that the seatbelt passed through the structure were non-deformable. Inspections of mounting locations were carried out after every test to ensure that deformation and damage did not occur. The anchorage locations mimicked that of an actual blast seat to reduce variation from test to test and to represent an actual occupant environment more closely.

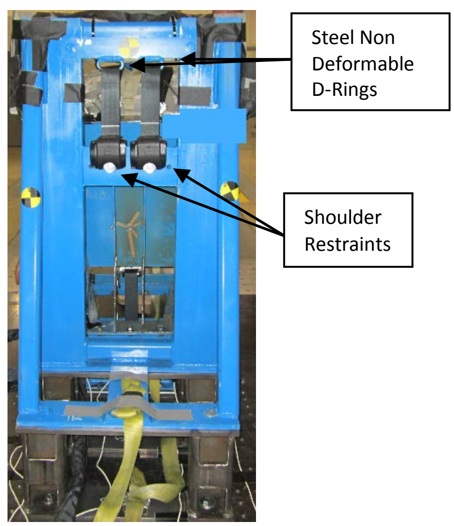

Figure 67: Shoulder Restraints Mounted On the Rigid Structure

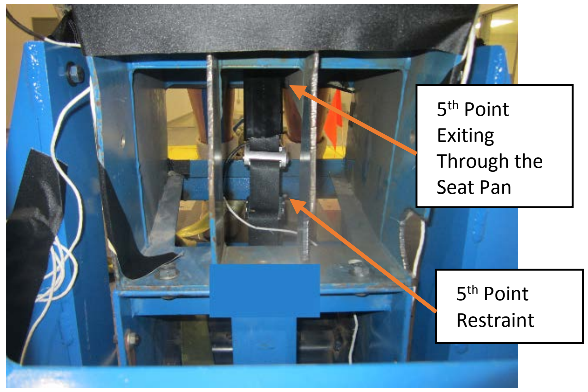

Figure 68: 5th Point Restraint Mounted Rigidly Onto the Sled (Rear View)

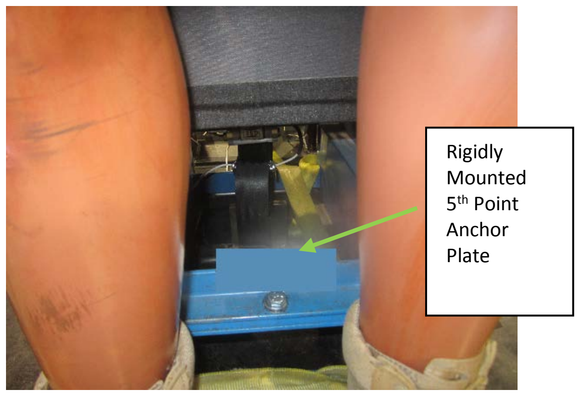

Figure 69: 5th Point Restraint Mounted Rigidly Onto the Sled (Frontal View)

ATD Utilization and Data Collection

A 50th percentile male ATD, with a SAW Gunner configuration encumbrance was used for the test series. An ATD is a calibrated test instrument used to measure human injury potential in vehicle crashes. The ATD simulates human response to impacts, accelerations, deflections, forces, and moments generated during a crash. Transducers in the dummy provide the physical levels experienced by the dummy. These readings are controlled and repeatable due to careful dummy design and manufacture so that the vehicle designer may use them to perfect the safety of the product[9]. Data on injury metrics, such as: HIC, chest resultant, chest deflection, neck FX (force in the X direction), neck MY (moment in the Y direction) and pelvis resultant were collected using a data acquisition system. The data were analyzed and a judgment of pass/fail was assigned per injury limits described in FMVSS 208 (Section 6)[1] and internal OCP TECD injury limits (not released for public use). Loads from the chest potentiometer were utilized to better understand and analyze chest to PPE interaction. ATD excursion measurements were taken at the head and knee during their maximum excursion via video analysis.

Restraint load cells were utilized to capture loads imparted onto the restraints from the ATD to analyze the effectiveness of the restraint system further. The restraint load cell is a calibrated device, which measures the tension exerted onto the webbing during a crash or blast event. The amount of load transferred onto the restraint system during a test is determined by the amount of tension. Lack of tension or a decrease in tension could indicate improper restraint or loss of restraint, which video analysis is not capable of capturing.

Encumbrance Selection

The encumbrance selected for this testing series was the SAW Gunner configuration. The SAW Gunner configuration adds roughly 30kg to the overall 50th percentile ATD weight. The result of this added weight contributes to the increase in total energy managed by the restraint. Added encumbrance also requires that additional webbing on spool is utilized to restrain the occupant. Figure 70 and Figure 71 highlight the Encumbrance as worn by the 50th Percentile ATD

Figure 70: Frontal View of Encumbrance

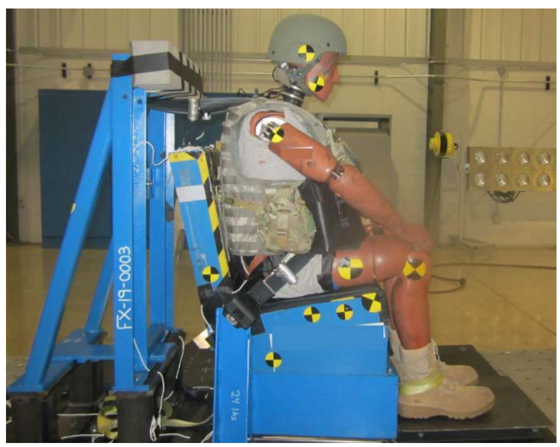

Figure 71: Overall Side View of ATD with Encumbrance

Restraint Routing Considerations

The initial test run had the restraints routed on top of the encumbrance. It was discovered that routing the restraints over gear would result in load anomalies in the restraint load cells and damage to gear. Figure 72 and Figure 73 highlight restraint routing prior to the test. Figure 74 and Figure 75 highlight the damage occurred to the encumbrance at the maximum excursion. Figure 76 and Figure 77 highlight load anomalies caused by the loading and unloading of the restraints onto the encumbrance.

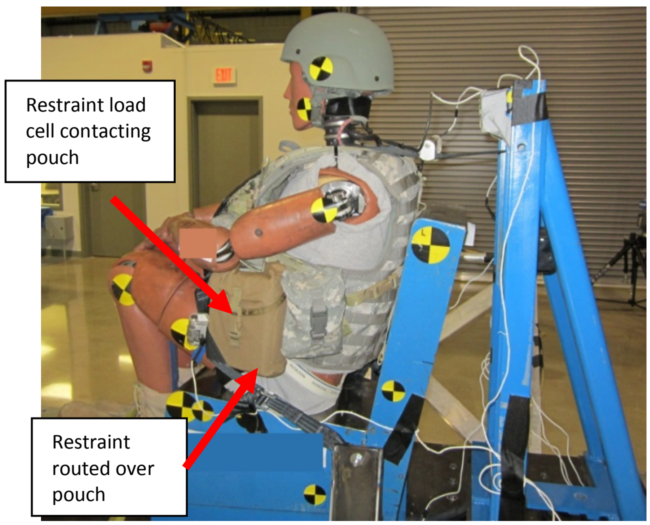

Figure 72: Left Side View of Restraint Routing

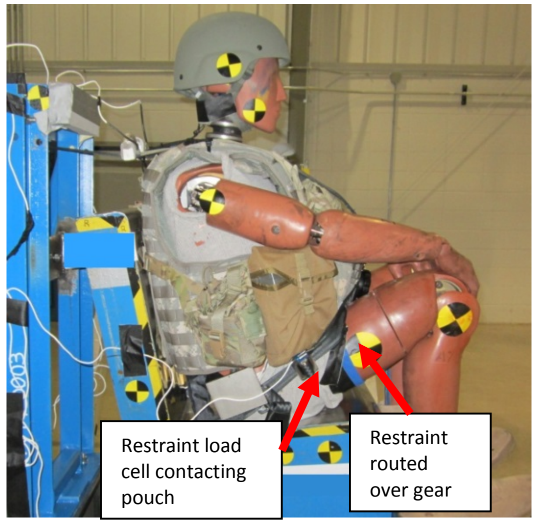

Figure 73: Right Side View of Restraint Routing

Figure 74: Left Side View at Maximum Excursion

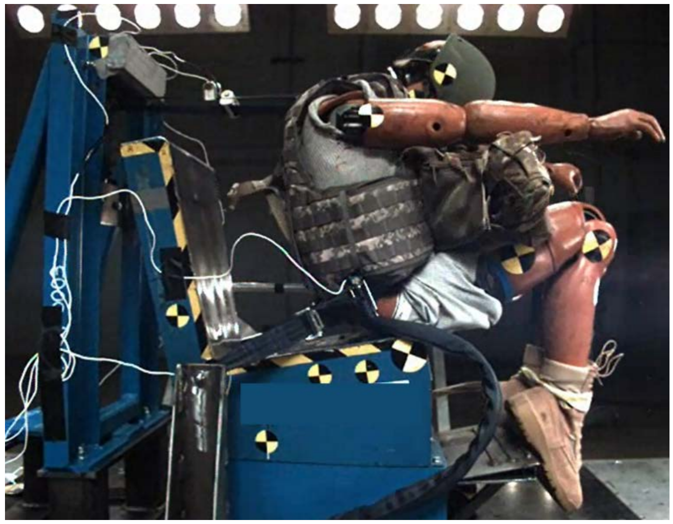

Figure 75: Right Side View at Maximum Excursion

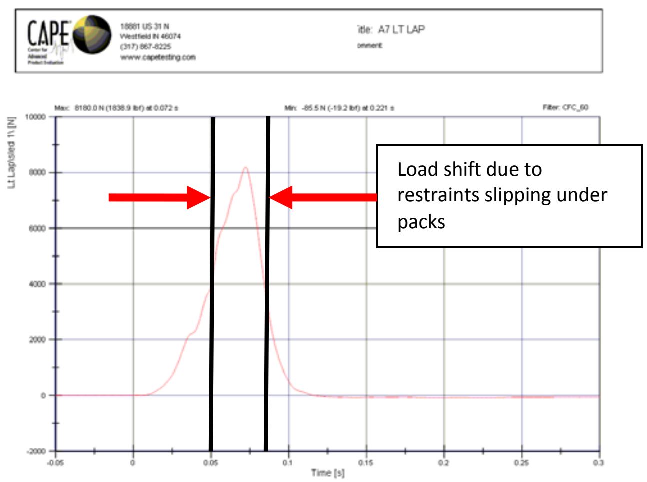

Figure 76: Left Lap Load Cell

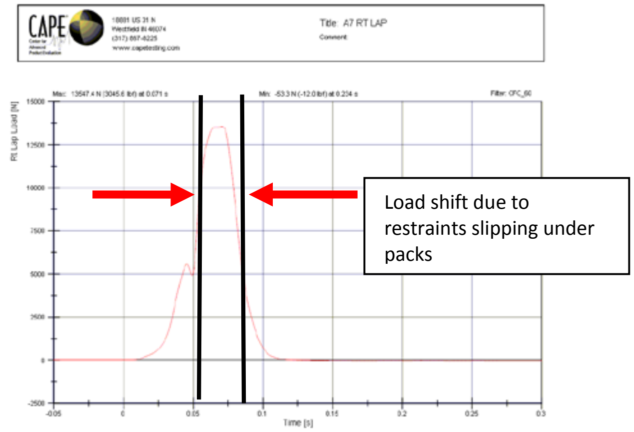

Figure 77: Right Lap Load Cell

After the test anomaly was discovered, all future testing was conducted with the restraints routed under the encumbrance. The load cells also were moved in a manner where they would no longer contact any surrounding surfaces that would alter the data. No damage to the gear or load cell anomalies was observed, with the new test setup shown in Figure 78 and Figure 79.

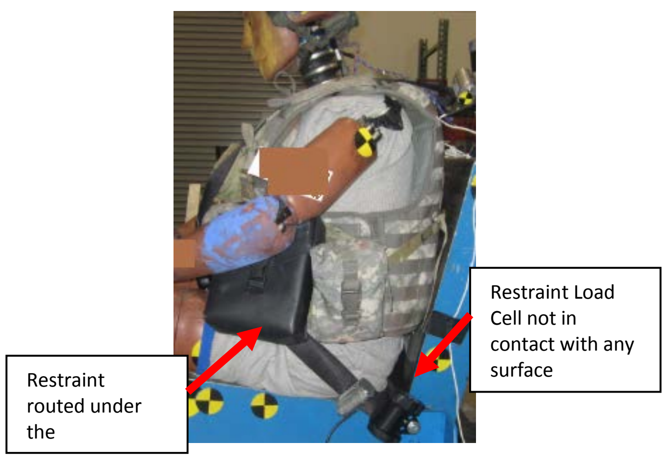

Figure 78: Left Side View of New Restraint Routing

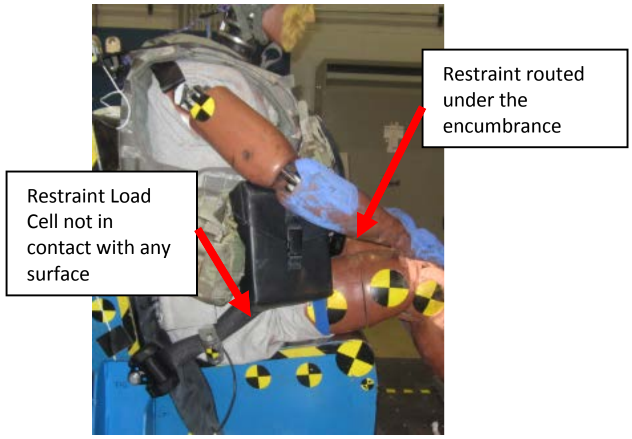

Figure 79: Left Side View of Restraint Routing

Military Pulse Creation and Comparison to the FMVSS 208 Pulse

The pulse created for the OCP TECD program was derived from internal U.S. Army modeling and simulation studies, historical crash data conducted prior to the inception of this project, and the comparison of FMVSS and other readily available crash pulses. Due to the rigidity of military vehicles and lack of frontal deformation, higher G forces were created and were taken into account with the development of this pulse. The final developed pulse for this program is captured in Figure 80.

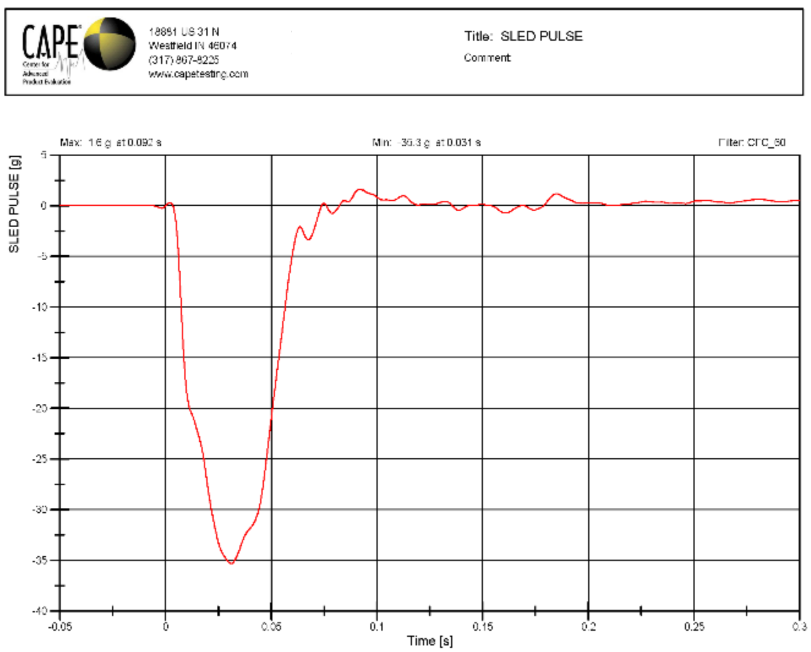

Figure 80: TARDEC DEVELOPED OCP TECD PULSE

The peak G of the TARDEC pulse was up to 20gs higher and spread over a shorter duration as compared to the 208 Pulse as seen in Figure 62. This is due to military vehicles being stiffer than passenger vehicles.

Testing Results

Gear Comparison

Initial sled test runs were conducted to determine the effects of the encumbrance on the restraint system and injury assessment values. The baseline test was run without gear and a second test was run with SAW Gunner encumbrance and helmet. Results indicate the gear load contributed to increased excursions and injury value changes on certain criterion. To understand the differences in displacement better, measurements were taken at the head and knee during their maximum excursion via video analysis. The maximum pelvic excursion of the encumbered ATD was 76mm greater than the unencumbered ATD as seen in Figure 81.

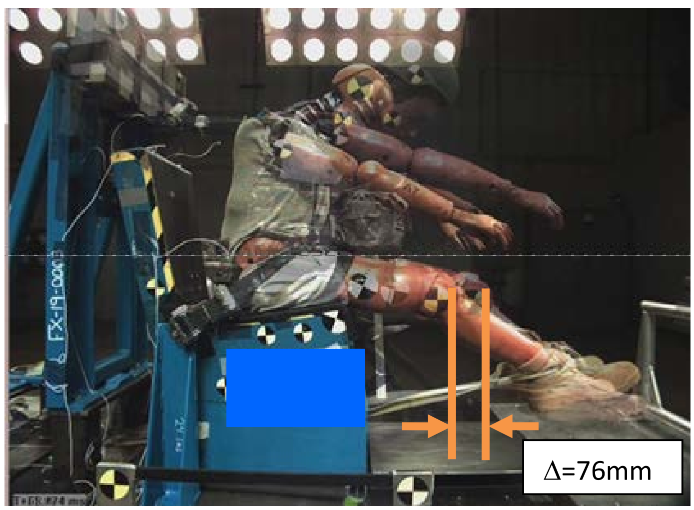

Figure 81: Maximum ATD Pelvic Excursion With and Without Gear

The maximum head excursion of the encumbered ATD was 54mm greater than the unencumbered ATD as seen in Figure 82. The restraint load cell values are shown below in Table 16.

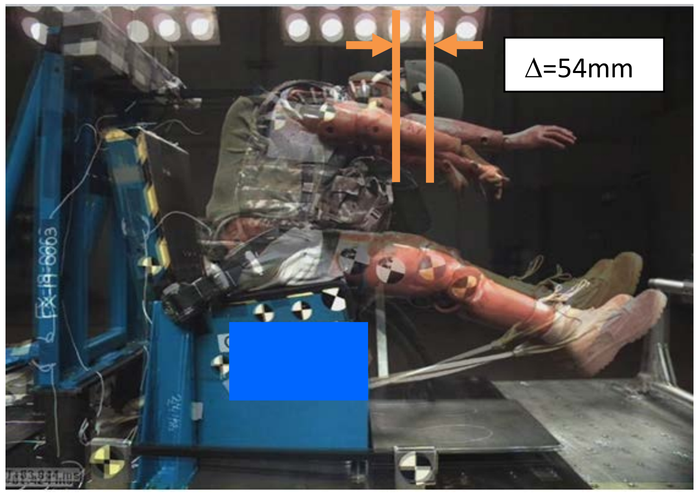

Figure 82: Maximum ATD Head Excursion With and Without Gear

Table 16: Load Cell Values Gear Study Comparisons

Gear Study TARDEC Pulse		
	w/o Gear (Baseline)	w/ Gear
Left Shoulder Load Cell (N)	9123	10588
Right Shoulder Load Cell (N)	5045	10653
Left Lap Load Cell (N)	8899	8457
Right Lap Load Cell (N)	9137	8300
5th Point Load Cell (N)	19764	13314
Total Load (N)	51968	51312

The injury values are shown below in Table 17.

Table 17: Gear Study Comparisons

Gear Study TARDEC Pulse		
	w/o Gear (Baseline)	w/ Gear
HIC 15	541	484
Chest Resultant (g)	76	61
Chest Deflect (mm)	21	66
Neck Fx (N)	1483	1550
Neck Fz (N)	3292	4216
Neck My (N-M)	123	172
Pelvis Resultant (g)	78	71

Pulse Comparison

To understand the effects of the encumbrance on the restraint loads and injury values a second series of tests were conducted to compare the difference between the TARDEC GSS developed pulse and the FMVSS 208 pulse. Two sled tests were conducted utilizing the SAW gunner gear. The FMVSS 208 pulse is considered baseline and the second pulse is with the more aggressive TARDEC GSS pulse.

Results show the more aggressive TARDEC pulse contributed to increased excursions and injury values on most criteria as is depicted in the data shown in Table 19. Measurements were taken at the head and knee during their maximum excursion via video analysis. The TARDEC pulse contributed to increased maximum pelvic excursion. The maximum pelvic excursion of the dummy with the TARDEC Pulse was 70mm greater than the FMVSS Pulse as seen in Figure 83. The maximum head excursion could not be calculated due to poor target visibility. The restraint load cell values are shown in Table 18.

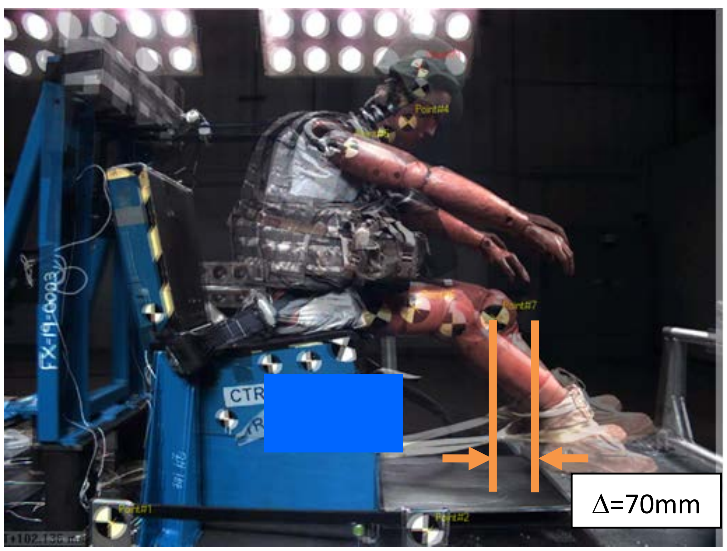

Figure 83: Maximum ATD Pelvic Excursion TARDEC vs. FMVSS 208 Pulse

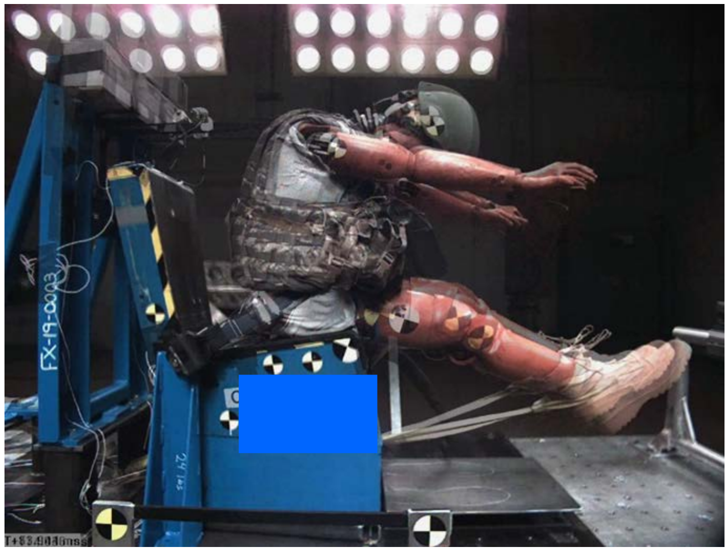

Figure 84: Maximum ATD Head Excursion TARDEC vs. FMVSS 208 Pulse

Table 18: Load Cell Values Pulse Study Comparisons

TARDEC Pulse Study		
	208 Pulse (Baseline)	TARDEC Pulse
Left Shoulder Load Cell (N)	6939	10588
Right Shoulder Load Cell (N)	6625	10653
Left Lap Load Cell (N)	4829	8457
Right Lap Load Cell (N)	4514	8300
5th Point Load Cell (N)	6245	13314
Total Load (N)	29152	51312

The injury assessment value increases are shown in Table 19

Table 19: Pulse Study Comparisons

TARDEC Pulse Study		
	208 Pulse (Baseline)	TARDEC Pulse
HIC 15	188	484
Chest Resultant (g)	34	61
Chest Deflect (mm)	55	66
Neck Fx (N)	1102	1550
Neck Fz (N)	2346	4216
Neck My (N-M)	92	172
Pelvis Resultant (g)	30	71

Discussion

Two unique test scenarios that related specifically to restraint systems and their interaction with encumbrance were analyzed. The test scenarios included: the variation of encumbrance on an occupant and pulse input variations on an encumbered occupant. In all of the scenarios, the gear provided for an increased amount of excursion and an escalation in many critical injury values.

Gear Comparison

When encumbered, the ATD is 30kg heavier than an unencumbered ATD. The SAW Gunner configuration in particular has pouches for storage located around the abdomen. In addition to the assigned encumbrance, the Soldiers were likely to add their own gear or "accessories" that further complicated weight ranges and occupant classification. Considerations for additional gear were out of scope for purposes of the study discussed in this report.

When the lap restraints are routed under the encumbrance, they are no longer restraining the encumbrance instead they are restraining the pelvis directly. The loads in the lap portion of the restraint system do not vary substantially between tests. This is not the case for the shoulder restraints or the 5th point restraint. Since routing the shoulder restraints under the encumbrance is not possible, it is critical to route it as close as possible to the gear. Restraint position is compounded by additional torso mass, which can contribute to the occupant displacing further. The shoulder restraints slow down the encumbrance while the chest and neck are still moving forward. As a result, the chest displacement continues to rise as it is loaded by the encumbrance as seen in Figure 85. Since the chest plate pushes onto the occupant's entire chest, the force of the restraints essentially pulls the entire chest plate rearwards causing the chest potentiometer to register greater displacement; the chest deflection increase of 214% was observed and shown in Table 21. The neck tensile force and moment rose as the head and neck rotated forward as seen in Figure 95 and Figure 96. The data channels in red are the baseline tests that did not include encumbrance. The data channels in blue are the tests that included the SAW Gunner encumbrance and helmet.

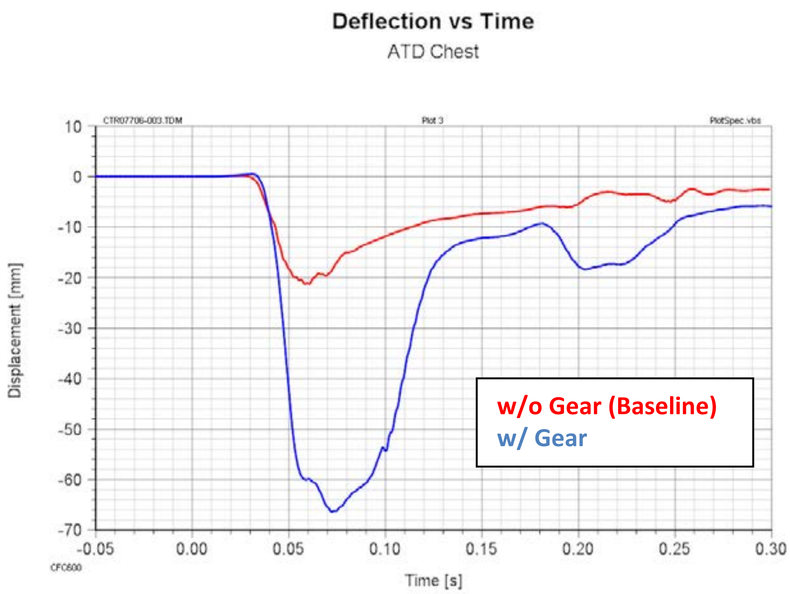

Figure 85: Chest Deflection

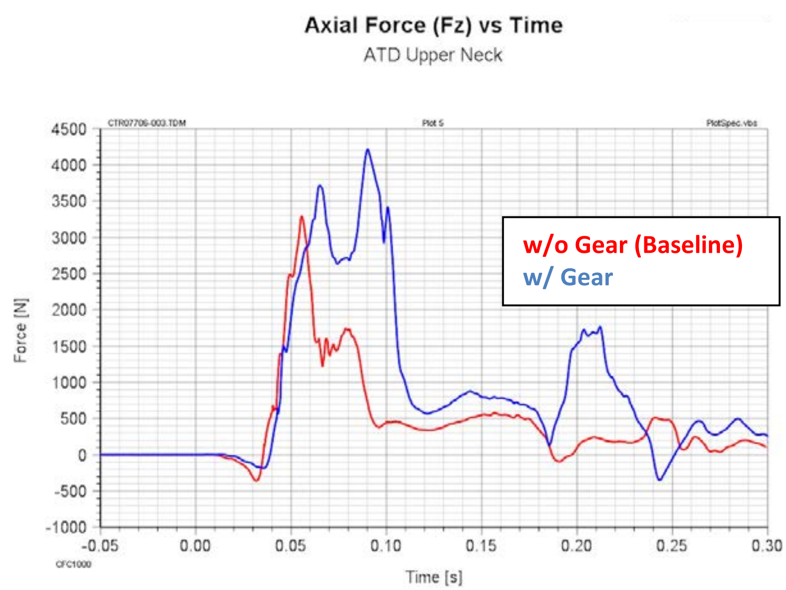

Figure 86: Neck Fz

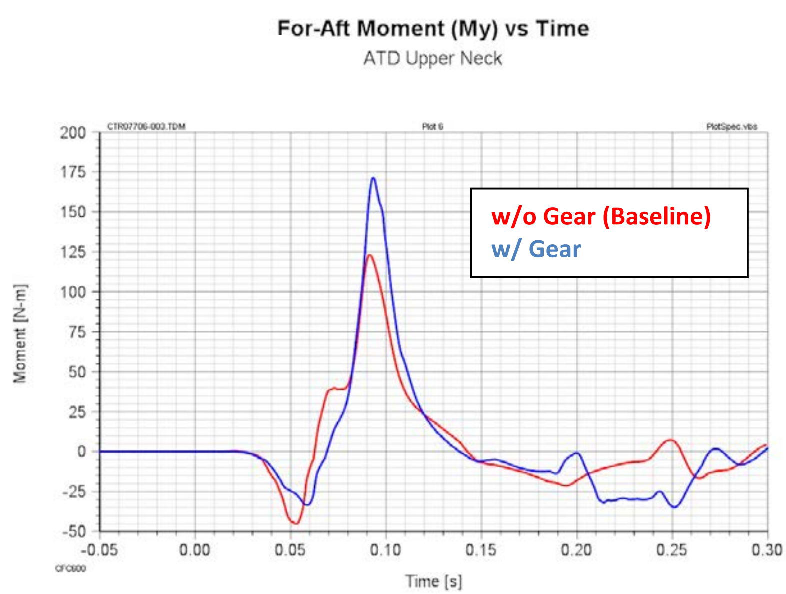

Figure 87: Neck My

Restraint loads and injury values are highlighted in Table 20 and Table 21. Right shoulder load cell in the baseline test do not match that of the left shoulder load cell. A review of the data and video failed to provide a clear explanation for the difference in the left and right shoulder belt load readings for the baseline test. The combined energy of all the load cells is the same between these two tests even though the overall distributions are different as shown in Table 20.

Table 20: Gear Study Restraint Load Comparisons

Gear Study TARDEC Pulse				
	w/o Gear (Baseline) (Graphed in Red)	w/ Gear (Graphed in Blue)	Delta	% Change from Baseline
Left Shoulder Load Cell (N)	9123	10588	1465	16.06%
Right Shoulder Load Cell (N)	5045	10653	5608	111.16%
Left Lap Load Cell (N)	8899	8457	-442	-4.97%
Right Lap Load Cell (N)	9137	8300	-837	-9.16%
5th Point Load Cell (N)	19764	13314	-6450	-32.64%
Total Load (N)	51968	51312	-656	1.26%

Table 21: Gear Study Injury Value Comparisons

Gear Study TARDEC Pulse				
	w/o Gear (Baseline) (Graphed in Red)	w/ Gear (Graphed in Blue)	Delta	% Change from Baseline
HIC 15	541	484	-57	-10.54%
Chest Resultant (g)	76	61	-12	-16.44%
Chest Deflect (mm)	21	66	45	214.29%
Neck Fx (N)	1483	1550	67	4.52%
Neck Fz (N)	3292	4216	924	28.07%
Neck My (N-M)	123	172	49	39.84%
Pelvis Resultant (g)	78	71	-7	-8.97%

The load cell value comparison graphs and injury value comparison graphs are found in Appendix I. The data channels in red are the baseline tests, which did not include encumbrance. The data channels in blue are the tests, which included the SAW Gunner encumbrance and helmet.

Pulse Comparison

Pulses developed by TARDEC were not based on one specific vehicle, however the culmination of historical data and M & S data that show that the crash decelerations experienced in a military vehicle crash would be high. The comparison tests between the TARDEC pulse and the FMVSS 208 pulse highlighted how the injury assessment values compared. Five of the injury values increased more than 50% for the TARDEC pulse, as shown in Table 23.

After reviewing the data, although the loads occur later in the crash events for the two pulses, they followed the same trends. For the less aggressive FMVSS crash pulse, the timing of the data traces were shifted to later in the event and had lower magnitudes. A change in pulse characteristics did not appear to have an effect on the chest (Figure 88) and neck (Figure 89 and Figure 90) reactions with the encumbrance. The data are shifted by about 3-5ms for the 208 Pulse as compared to that of the TARDEC Pulse. In addition, all the injury measurement loads increased by a minimum of 20% and as high as 157% as shown in Table 23.

As shown in Figure 91-Figure 95, restraint loads appeared to increase as the crash pulse was made more aggressive. The data are shifted by about 3-4ms for the 208 Pulse as compared to that of the TARDEC Pulse. In addition, all the load cell data increased by a minimum of 52% and as high as 115%. As shown in Table 22, the overall energy for the load cells increased by 76%. The following data channels in red are the FMVSS 208 Pulse baseline test. The data channels in blue are the TARDEC Pulse test.

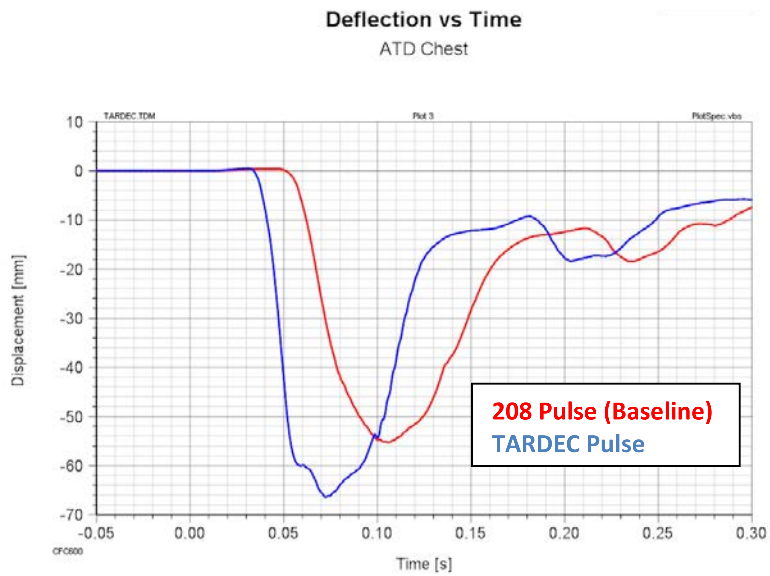

Figure 88: Chest Deflection

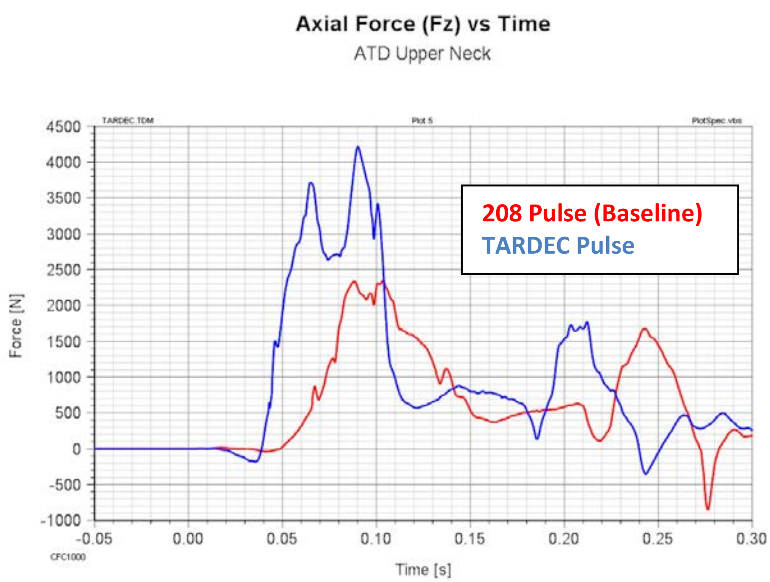

Figure 89: Neck Fz

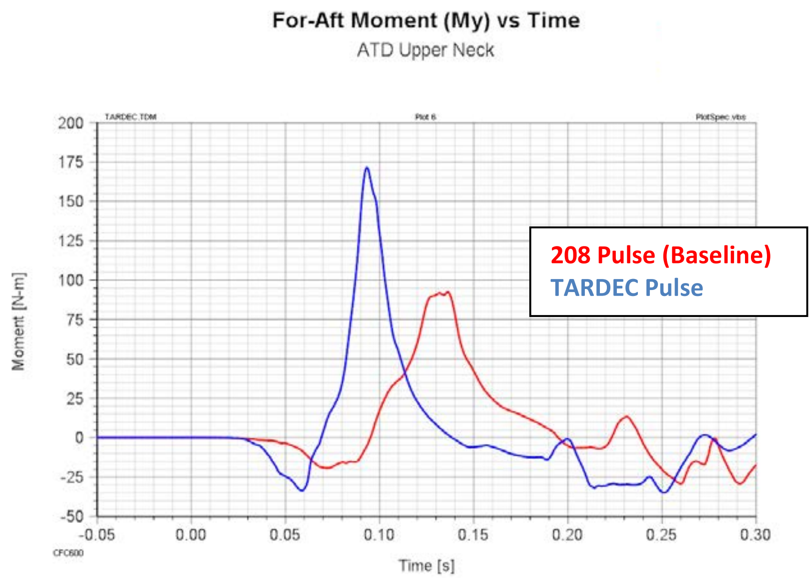

Figure 90: Neck My

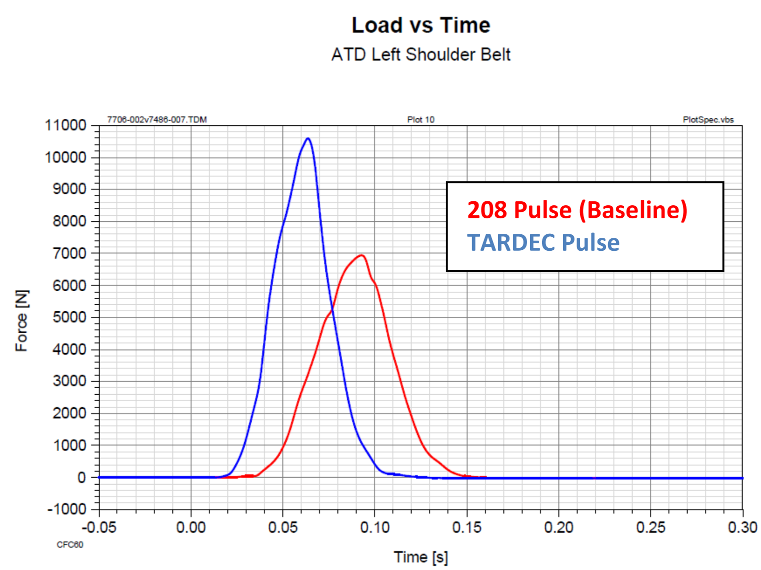

Figure 91: Left Shoulder Belt Load Cell Data

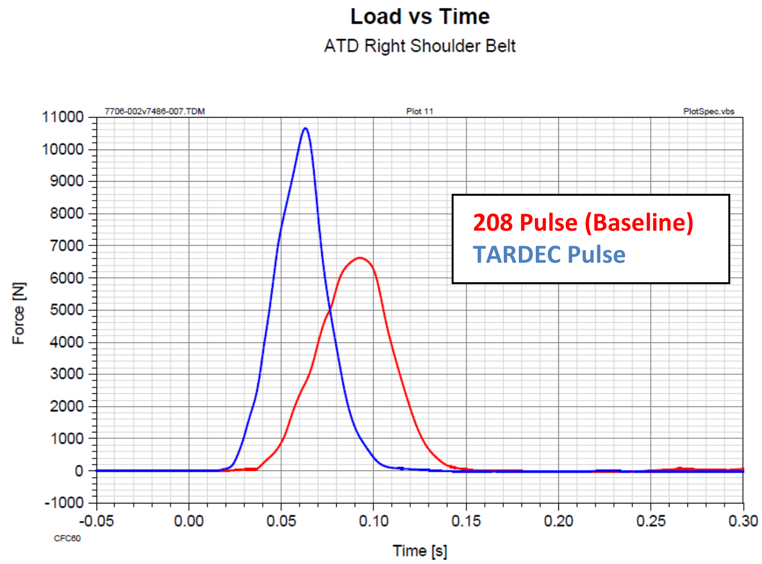

Figure 92: Right Shoulder Belt Load Cell Data

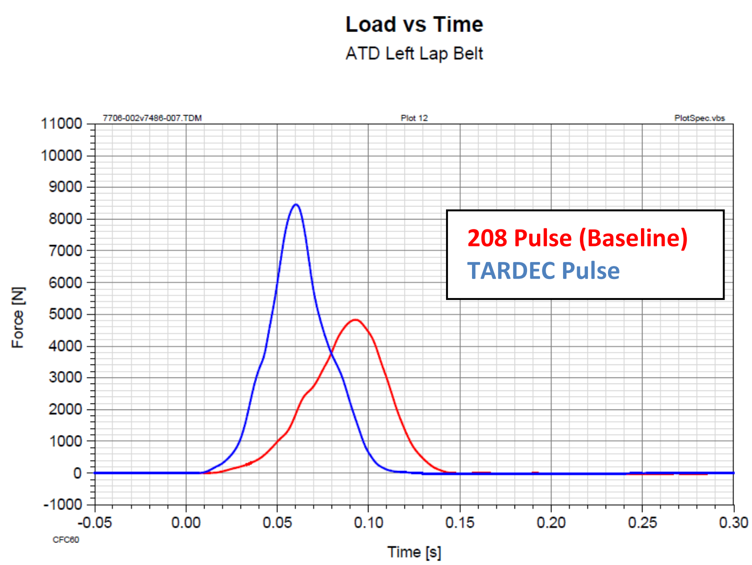

Figure 93: Left Lap Belt Load Cell Data

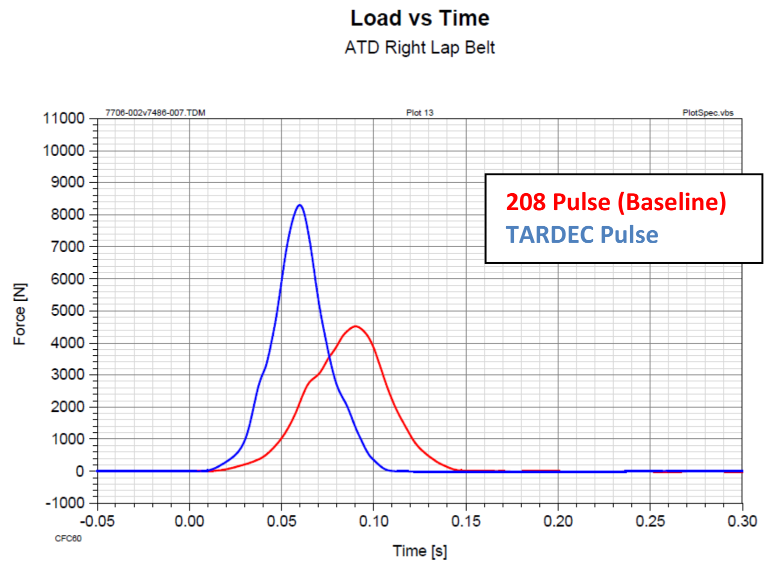

Figure 94: Right Lap Belt Load Cell Data

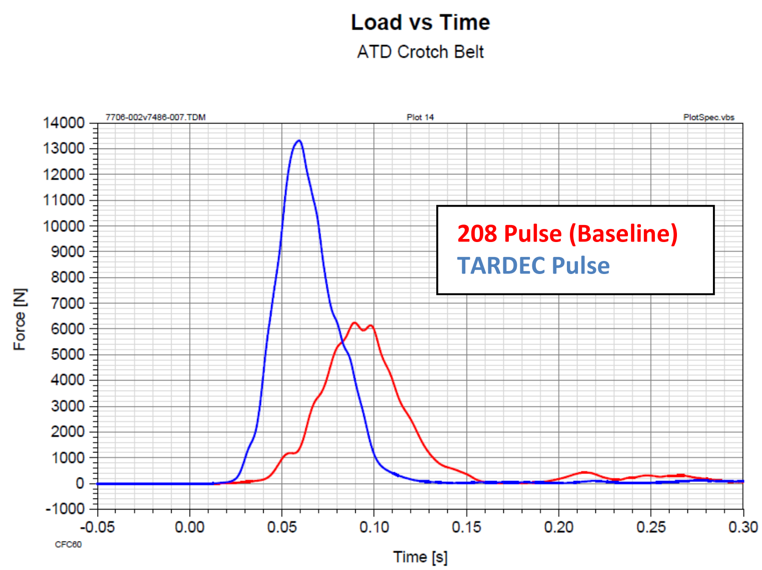

Figure 95: 5th Point Belt Load Cell Data

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Table 22: Pulse Study Restraint Load Comparisons

TARDEC Pulse Study				
	208 Pulse (Baseline) (Graphed in Red)	TARDEC Pulse (Graphed in Blue)	Delta	% Change from Baseline
Left Shoulder Load Cell (N)	6939	10588	3649	52.59%
Right Shoulder Load Cell (N)	6625	10653	4028	60.80%
Left Lap Load Cell (N)	4829	8457	3628	75.13%
Right Lap Load Cell (N)	4514	8300	3786	83.87%
5th Point Load Cell (N)	6245	13314	7069	113.19%
Total Load (N)	29152	51312	22160	76.02%

Table 23: Pulse Study Injury Value Comparisons

TARDEC Pulse Study				
	208 pulse (Baseline) (Graphed in Red)	TARDEC Pulse (Graphed in Blue)	Delta	% Change from Baseline
HIC 15	188	484	296	157.45%
Chest Resultant (g)	34	61	27	79.41%
Chest Deflect (mm)	55	66	11	20.00%
Neck Fx (N)	1102	1550	448	40.65%
Neck Fz (N)	2346	4216	1870	79.71%
Neck My (N-M)	92	172	80	86.96%
Pelvis Resultant (g)	30	71	41	136.67%

The load cell value comparison graphs and injury assessment value comparison graphs are found in Appendix J. The data channels in red are the FMVSS 208 Pulse baseline test. The data channels in blue are the TARDEC Pulse test.

Conclusions

The TARDEC frontal pulse reflected the characteristics of a rigid vehicle. The additional weight that a Soldier is required to carry creates a total occupant weight greater than is commonly tested for in the automotive industry. The combination of high weight and an aggressive, sustained pulse can generate forces higher than are typically designed by restraint manufactures. Mandatory gear sets that Soldiers wear do not create optimal situations for occupants to restraint coupling. The restraints under load can travel into spaces of the encumbrance and cause a delayed coupling effect that adds to forward excursion. Belts should be directly in contact with the occupant's body for best retention results in a crash event. For an optimal restraint performance, the restraint would be worn underneath the encumbrance; however, this is impractical for real-world use as it impairs rapid egress of the Soldier.

Seat designs in terms of rigidity, seat recline angles, seat pan angles, seat friction and surrounding impact surfaces also may influence occupant injury and should be considered in the design of the vehicle. This design is the focus of an occupant centric design.

The results of this study revealed that encumbrance can become damaged and load anomalies may exist when restraints are routed improperly. Higher chest displacements are encountered when encumbrance is used, with the encumbrance causing the neck to extend as the head rotates forward.

Pulses that are less aggressive cause timing of the injuries to shift and have lower magnitudes. Pulses do not appear to have an effect on neck and chest reactions with an encumbered occupant. Restraint loads appear to increase, as the crash pulse is made more aggressive

Chapter 5

IP Design and Evaluation on an Encumbered Soldier in a Frontal Crash Environment

Introduction

To understand the potential of reducing occupant injuries better, an impact surface / IP was utilized to evaluate the effects of Soldier gear encumbrance on restraints. TARDEC GSS together with IMMI created an impact surface to mimic an actual military vehicle IP. The IP design selected was based on the energy absorption characteristics and design found on production class 8 tractors, which are similar to those found in military vehicles.

Test Methodology

Test Setup

Frontal decelerations present a unique challenge to an occupant restraint system when compared to that of blast or rollover conditions. Although blast and rollover events are violent and traumatic, blast events may be managed more effectively through a seat energy absorbing system rather than a restraint system. Rollover injury mitigation may be managed more effectively through energy attenuating technologies, such as the use of air bags or energy attenuating materials that are beyond the scope of this effort. It was anticipated that the added encumbrance to the existing 50^{th} percentile ATD in a frontal crash event would produce higher injury values and potentially push the restraint components beyond the original design intended for the automotive market. Designing a restraint to work effectively for this gear load could provide adequate restraint for other, less cumbersome, less massive gear loads.

The frontal sled test series used for this effort utilized a rigid seat mounted on a servo-hydraulic sled. The sled was propelled by an open-loop pneumatic actuator and the acceleration profile was controlled by a closed-loop 10 kHz hydraulic servo-brake. Figure 96 illustrates the principle of the sled and Figure 97 shows the actual sled utilized for testing.

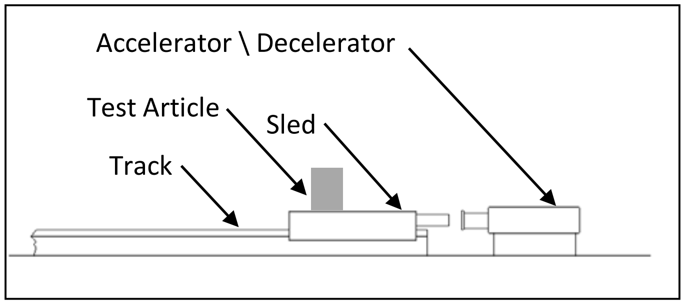

Figure 96: Crash Sled

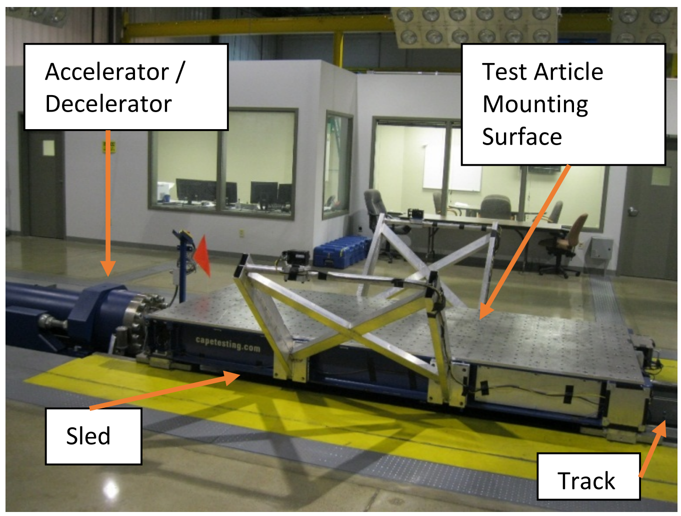

Figure 97: Servo-Hydraulic Sled

A modified rigid steel seat similar to the type used for ECE R16 compliance testing was used in this study to reduce test related experimental variation that may occur when using a conventional blast test seat. Two restraint systems were used for testing purposes. The restraints used for this study included a 5-point occupant restraint with "ReadyReach." Figure 98 depicts a typical military style 5-Point restraint system, which was designed to distribute the restraint load across the occupant's torso and limits occupant movement through an additional restraint located between the occupant's legs that typically is anchored to the seat bottom. Features of the FMVSS 209 and 302 compliant 5-Point restraint include:

1. Dual retractable shoulder restraint straps with dual severe duty emergency locking retractors (ELRs)

2. Dual retractable lap restraint straps (ALRs) with dual automatic locking retractors

3. Anti-submarining 5th point restraint strap with magnesium rotary buckle and rapid release lever, manual pull-tab style adjuster

4. Black polyester webbing with 6,000 lbs. minimum breaking strength

Figure 98: 5-Point Restraint

Figure 99 depicts the ReadyReach restraint system that presents the shoulder belts and lap belts outward, making them easier to reach for the occupant. Figure 100depicts the test set-up for the shoulder restraint system that restrains the occupant mainly with contact to the front torso at the point of the shoulders when mounted on the rigid seat.

Figure 99: ReadyReach Restraint System

Modifications to the sled test set-up included reinforcements to accommodate additional restraint anchorages required for a 5-Point harness restraint system. The seat back angle was set to 10° from vertical and seat pan angle was set to 10° from horizontal, and remained fixed throughout the test series. The H-Point (Hip location) was set to (X=195.7mm, Y=-86.6mm and Z=-384.5mm) with the origin point being set to (0,0,0) and located on the sled.

The restraint system was anchored to structures that were fixed to the sled as shown in Figure 100, Figure 101, and Figure 102. Furthermore, all anchor points and areas that the seatbelt passed through the structure were non-deformable. Inspections of mounting locations were carried out after every test to ensure that deformation and damage did not occur. The anchorage locations mimicked that of an actual blast seat to reduce variation from test to test and to represent an actual occupant environment more closely.

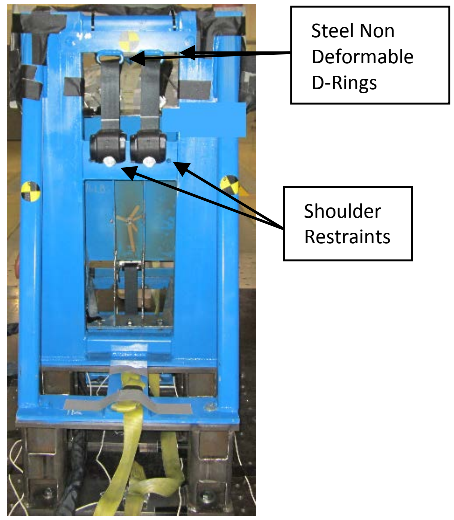

Figure 100: Shoulder Restraints Mounted On the Rigid Structure

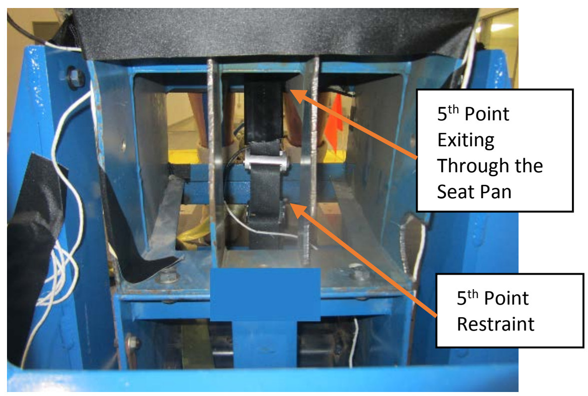

Figure 101: 5th Point Restraint Mounted Rigidly Onto the Sled (Rear View)

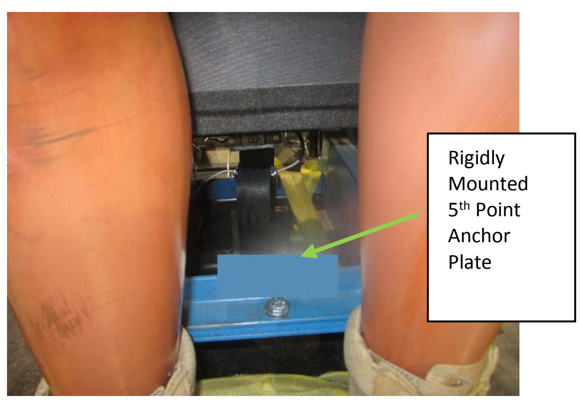

Figure 102: 5th Point Restraint Mounted Rigidly Onto the Sled (Frontal View)

ATD Utilization and Data Collection

A 50th percentile male ATD, with a SAW Gunner configuration encumbrance was used for the test series. An ATD is a calibrated test instrument used to measure human injury potential in vehicle crashes. The ATD simulates human response to impacts, accelerations, deflections, forces, and moments generated during a crash. Transducers in the dummy provide the physical levels experienced by the dummy. These readings are controlled and repeatable due to careful dummy design and manufacture so that the vehicle designer may use them to perfect the safety of the product[9]. Data on injury metrics, such as: HIC, chest resultant, chest deflection, neck FX (force in the X direction), neck MY (moment in the Y direction) and pelvis resultant were collected using a data acquisition system. The data were analyzed and a judgment of pass/fail was assigned per injury limits described in FMVSS 208 (Section 6)[1] and internal OCP TECD injury limits (not released for public use). Loads from the chest potentiometer were utilized to better understand and analyze chest to PPE interaction. ATD excursion measurements were taken at the head and knee during their maximum excursion via video analysis.

Restraint load cells were utilized to capture loads imparted onto the restraints from the ATD to analyze the effectiveness of the restraint system further. The restraint load cell is a calibrated device, which measures the tension exerted onto the webbing during a crash or blast event. The amount of load transferred onto the restraint system during a test is determined by the amount of tension. Lack of tension or a decrease in tension could indicate improper restraint or loss of restraint, which video analysis is not capable of capturing.

IP Design

During the sled series, understanding the effects of adding an IP to current military vehicle designs was important. An impact surface mimicking what could be used in an actual military vehicle IP was created. The IP utilized energy absorption characteristics based on the production class 8 tractors. The IP consists of a composite structure of EPS foam. The structure supporting the foam is built very rigidly similar to rigid military vehicle interiors. The rigid structure requires the EA foam in the knee bolster of the IP to act as the primary energy absorption mechanism. Figure 103 through Figure 105 show a typical design of current military vehicle IP's (Figure 103) and in Figure 104 and Figure 105, the new TARDEC GSS IP design with the addition of an EA knee bolster.

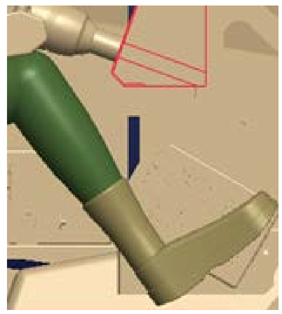

Figure 103: CAD of an Existing Military Vehicle IP

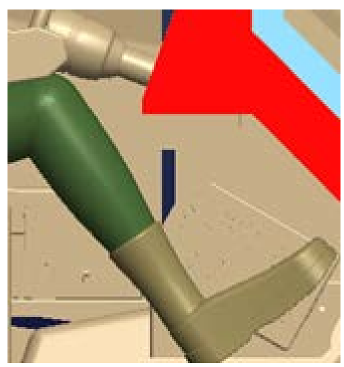

Figure 104: CAD of an Existing Military Vehicle IP with the Proposed Impact Surface Overlaid

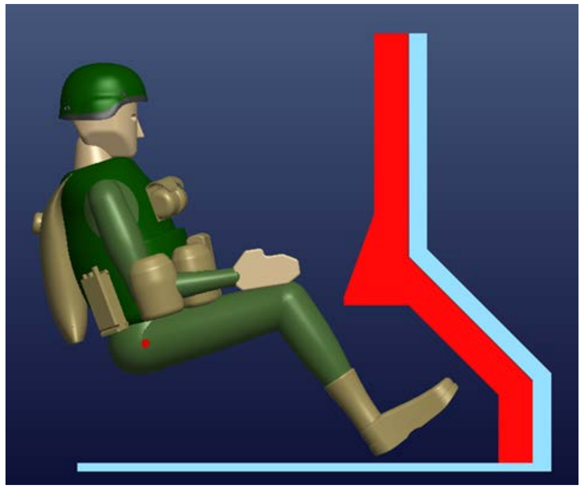

Figure 105: CAD of Initially Designed Impact Surface

Testing was conducted with a foot position typical to military vehicle occupants with the feet flat on the ground. In contrast, the FMVSS 208 seating procedures required the feet to be positioned upwards at an angle. For this study, it was assumed that Soldiers had their feet flat on the floor. Figure 106 is a depiction of existing military IP with the proposed knee impact surface added in black. Figure 107 shows the knee impact surface utilized in this test series and Figure 108 captures the secondary impact surface used in this test series.

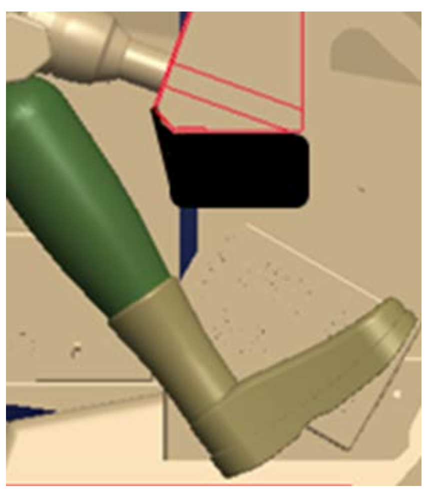

Figure 106: CAD of an Existing Military Vehicle IP

Figure 107: Knee Effect Surface

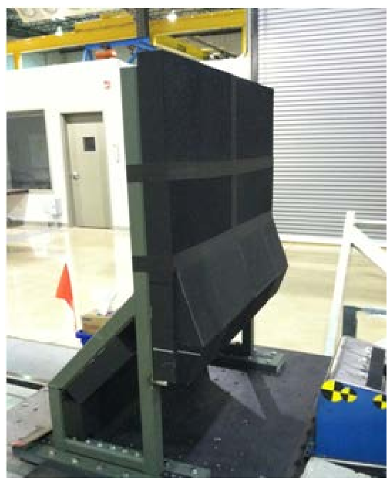

Figure 108: Secondary Impact Surface

Results

A series of sled tests included a simulated IP. Typically IPs throughout the ground transportation industry were designed with some energy absorption capabilities. Figure 109 and Figure 110 illustrate the system level design utilized in the initial IP design sled test.

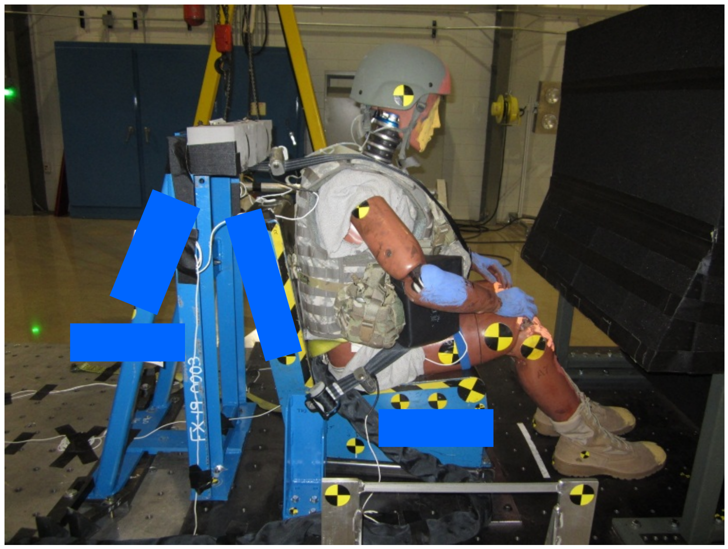

Figure 109: Side View of Test Setup with Initial IP Setup

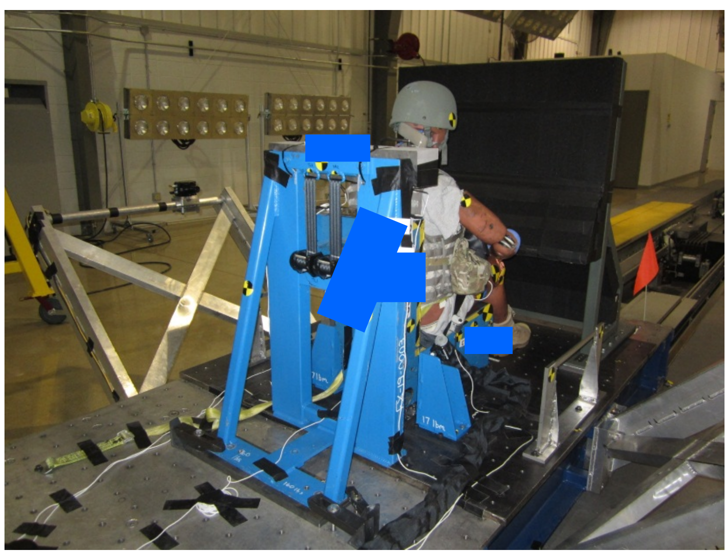

Figure 110: Oblique View of Test Setup with Initial IP Setup

A foam configuration was constructed that mimicked the angle of the front of the knees, providing optimal knee alignment. Results indicated decreased restraint loads with the inclusion of the EA foam in the knee bolster as shown in Table 24. In one test injury values increased in the femur. Femur loads increased substantially as shown in Table 25. Figure 111 illustrated the loading of the ATD into the IP design sled test.

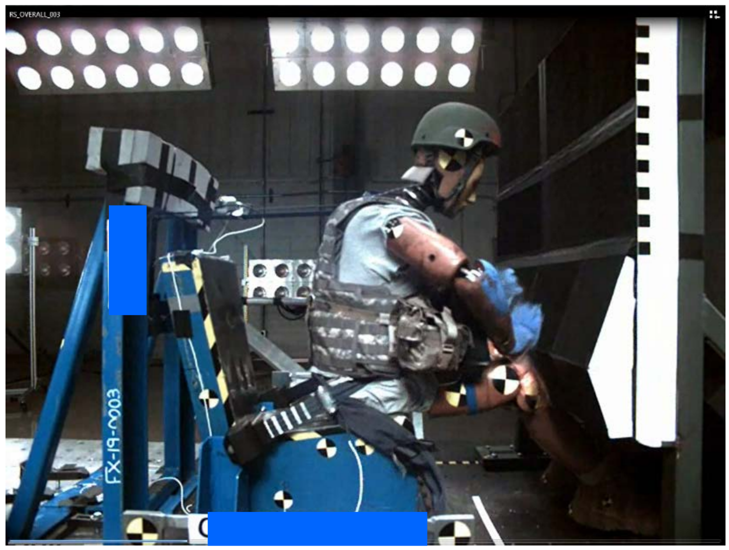

Figure 111: Maximum ATD Excursion into Redesigned IP Setup

The restraint load cell values are shown below in Table 24.

Table 24: Load Cell Values Pulse Study Comparisons

IP Study (Baseline / Final IP Config)		
	No IP **(GRAPHED IN BLUE)**	IP Redesign **(GRAPHED IN RED)**
Left Shoulder Load Cell (N)	10588	9645
Right Shoulder Load Cell (N)	10653	9269
Left Lap Load Cell (N)	8457	4830
Right Lap Load Cell (N)	8300	5391
5th Point Load Cell (N)	13314	16189

The load cell value comparison graphs are found in Figure 112-Figure 116. The data channels in blue are baseline tests with no IP. Differences in the shoulder belt load cell responses can be observed at 50ms as shown in Figure 112 and Figure 113. The lap belts exhibited delays in load when the IP was included in the setup as observed in Figure 114 and Figure 115. The 5th point transfers the load to the IP at 50ms as shown in Figure 116.

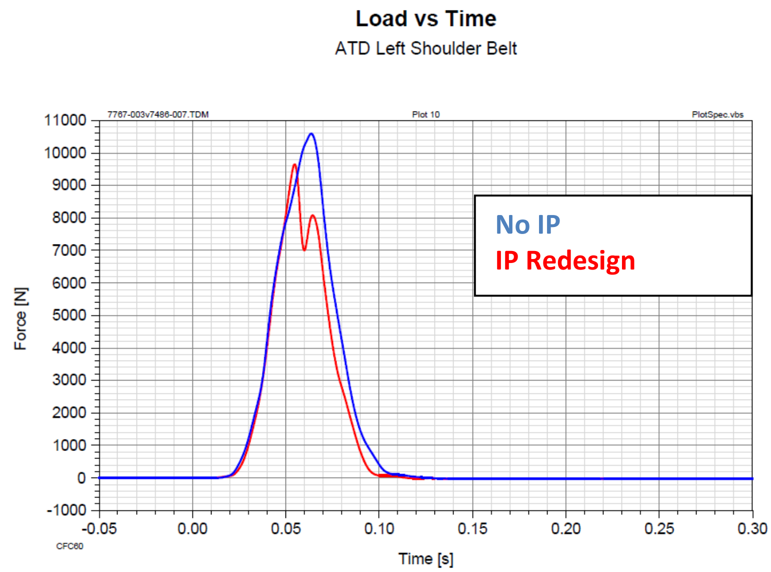

Figure 112: Left Shoulder Belt Load Cell Data

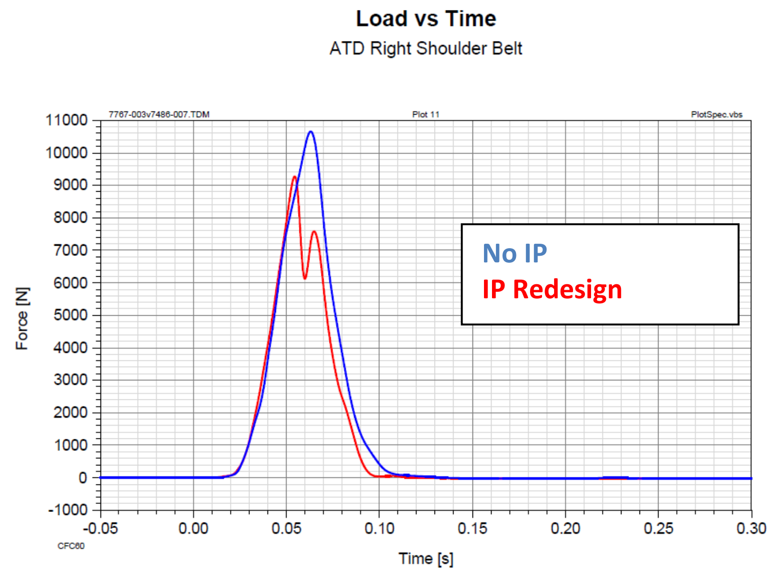

Figure 113: Right Shoulder Belt Load Cell Data

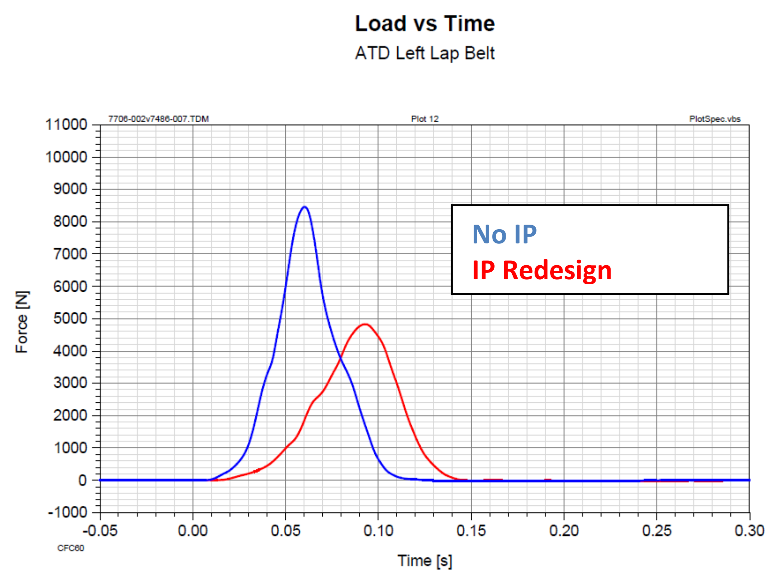

Figure 114: Left Lap Belt Load Cell Data

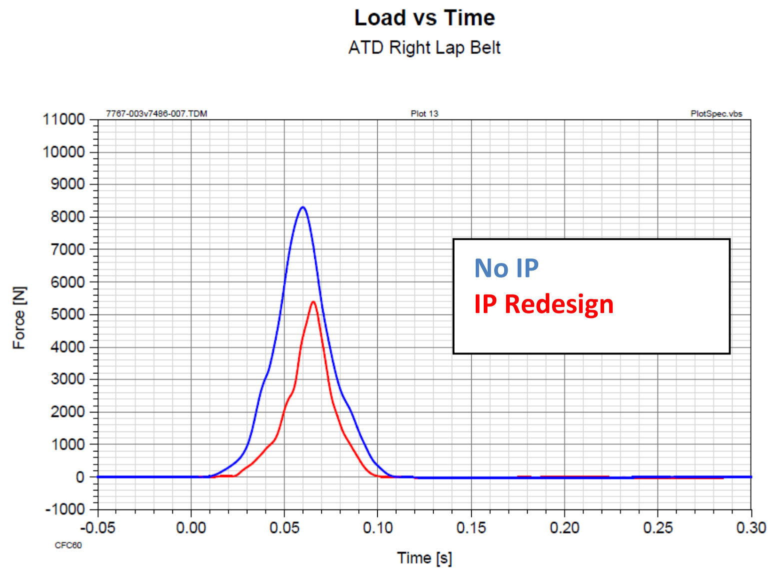

Figure 115: Right Lap Belt Load Cell Data

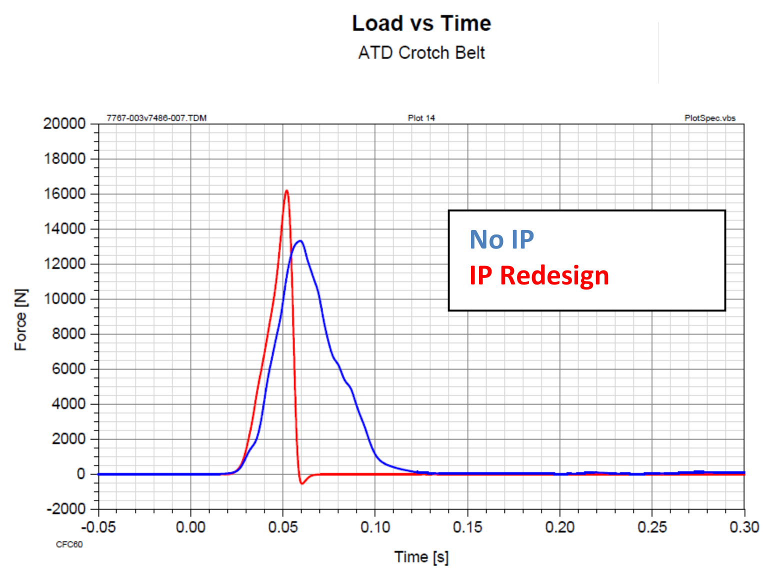

Figure 116: 5th Point Belt Load Cell Data

The Injury value increases and decreases are shown in Table 25.

Table 25: IP Study Comparisons

IP Study (Baseline / Final IP Config)		
	No IP **(GRAPHED IN BLUE)**	IP Redesign **(GRAPHED IN RED)**
HIC 15	484	580
Chest Resultant (g)	61	74
Chest Deflect (mm)	66	51
Neck Fx (N)	1550	1501
Neck Fz (N)	4216	3832
Neck My (N-M)	172	127
Pelvis Resultant (g)	71	123
Femur Loads (N) Ave L&R	Not collected	6567

The injury value comparison graphs are found in Figure 117 through Figure 123. The data channels in blue are the Baseline tests with no IP. The data channels in red are the IP Redesign tests. As shown in the test series with the installed IP, some occupant loads were transferred through the femurs. This was apparent by the decreases in the chest and neck. Head acceleration increased, chest displacement decreased and pelvis acceleration increased. In the videos the hands contacted the IP and some of the load may have been carried by the arms contributing to a decrease in chest deflection.

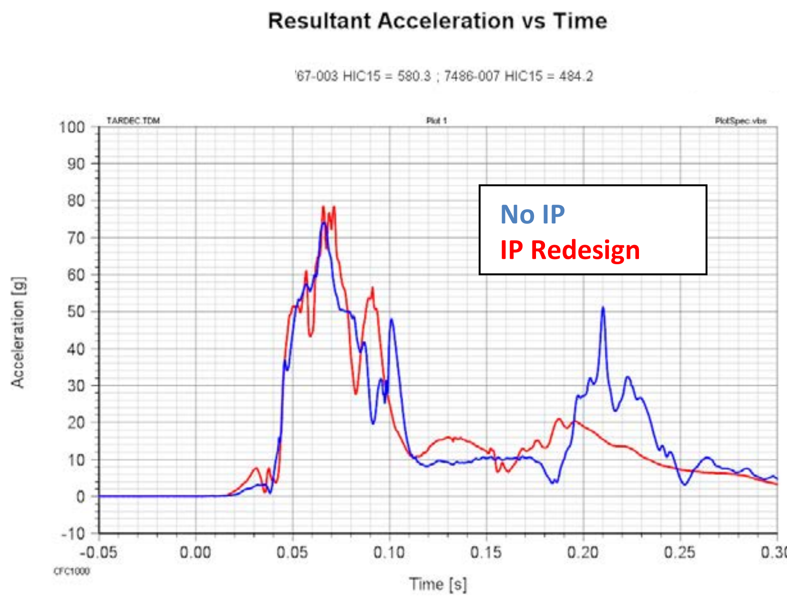

Figure 117: Head Resultant

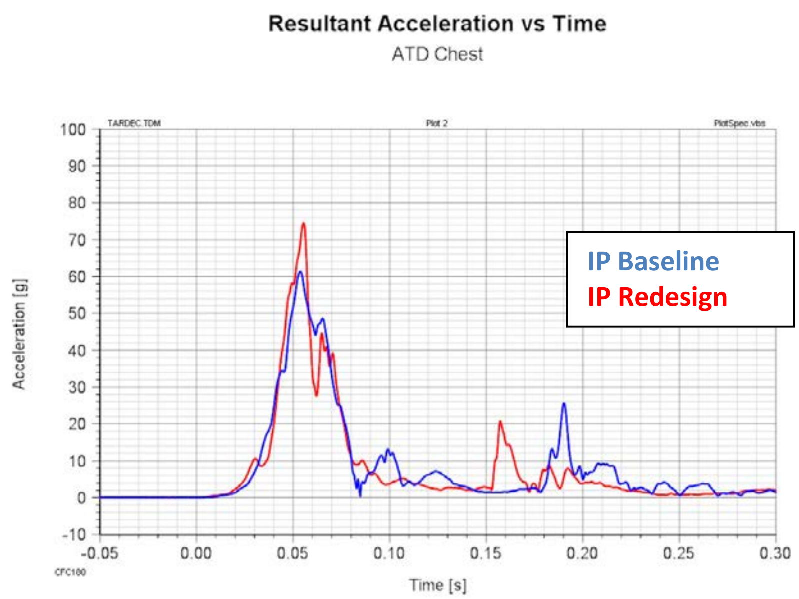

Figure 118: Chest Resultant

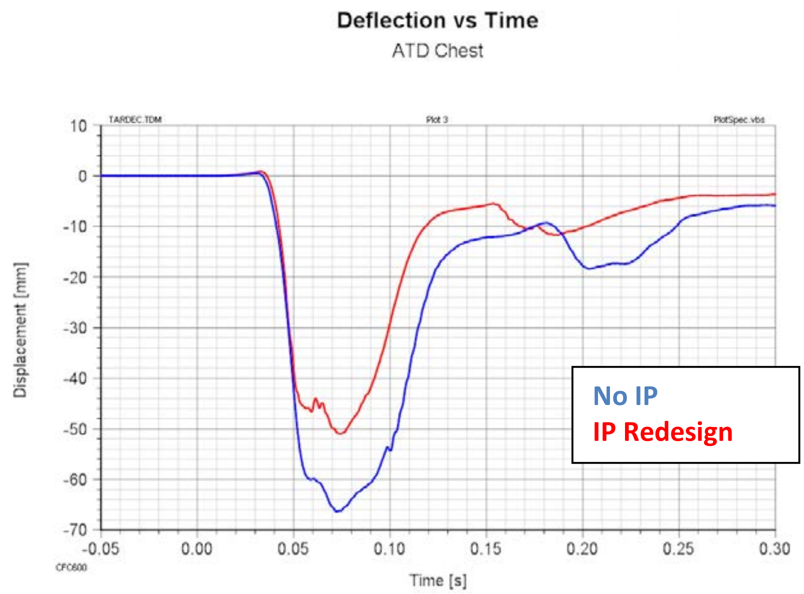

Figure 119: Chest Deflection

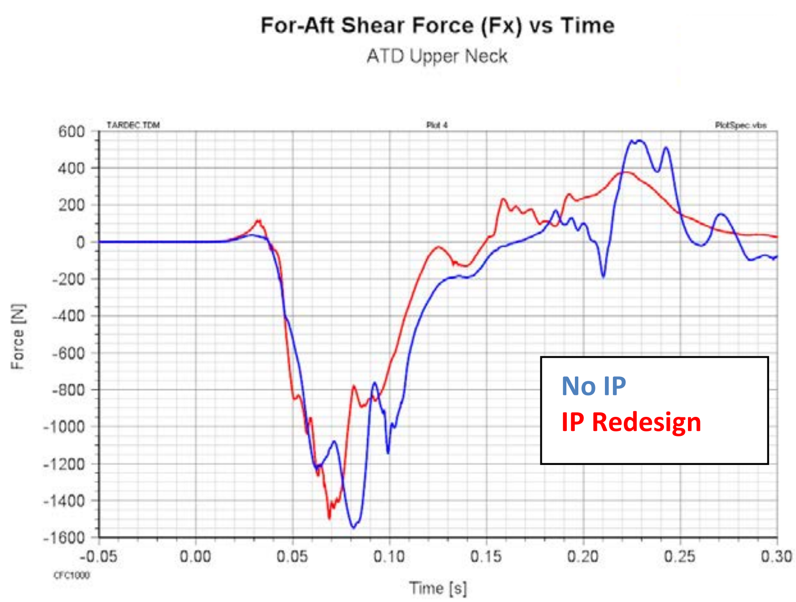

Figure 120: Neck FX

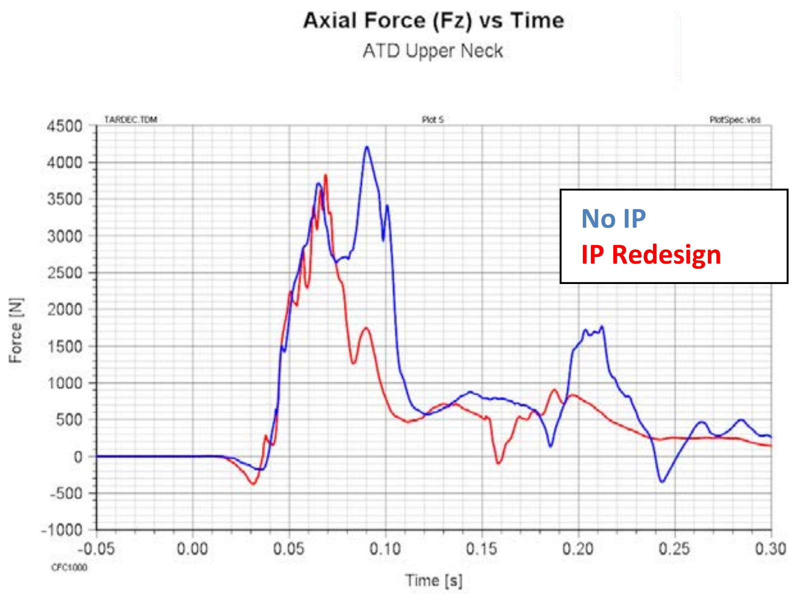

Figure 121: Neck Fz

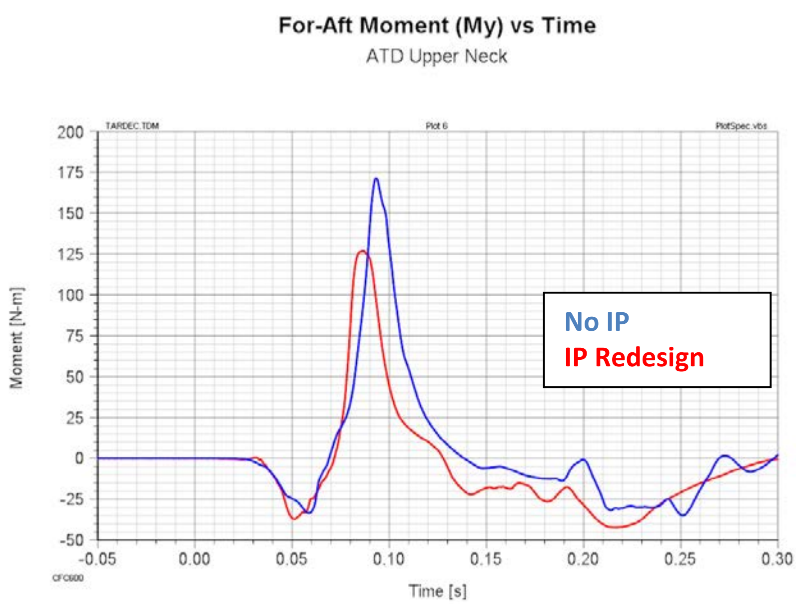

Figure 122: Neck My

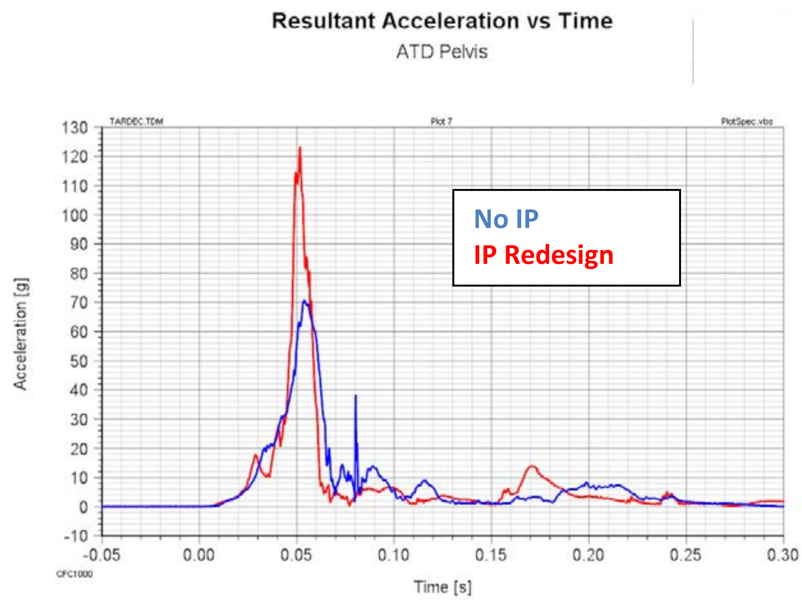

Figure 123: Pelvis Resultant

Discussion

Current military vehicle interiors have a high potential for occupant injury as a result of frontal impacts. The lack of secondary impact surfaces increase the likelihood that occupants could displace further during a crash event, leaving the restraint system to carry the entire load. This could lead to an increase of injury values. A properly designed and placed secondary impact surface has the potential to redistribute that load across that surface and thereby reduce the burden on the restraint system.

After running an initial sled test, the occupant knees ended up going under the IP as shown in Figure 124. The reason for this was because the CAD of the military vehicle that was utilized to design the IP had the seat sitting higher than the seat in the sled test series.

Figure 124: Maximum ATD Excursion into Initial IP Setup

As shown in the test series with the installed IP, some occupant loads were transferred through the femurs. This was apparent by decreases in the chest and neck. Head acceleration increased, chest displacement decreased and pelvis acceleration increased. In the videos, it is apparent that the hands contacted the IP and some of the load may have been carried by the arms contributing to a decrease in chest deflection. In the test series with the IP, differences in the shoulder belt load cell responses can be observed at 50ms as shown in Figure 112 and Figure 113. The 5th point unloads immediately at the time the loads transfer to the IP as shown in Figure 116. Onset of loading of the lap belts was delayed when the IP was included in the setup as observed in Figure 114 and Figure 115. The data from this test series were tabulated in Table 26 and Table 27.

Table 26: IP Study Restraint Load Comparisons

IP Study (Baseline / Final IP Config)				
	Baseline	IP Redesign	Delta	% Change from Baseline
Left Shoulder Load Cell (N)	10588	9645	-943	-8.91%
Right Shoulder Load Cell (N)	10653	9269	-1384	-12.99%
Left Lap Load Cell (N)	8457	4830	-3627	-42.89%
Right Lap Load Cell (N)	8300	5391	-2909	-35.05%
5th Point Load Cell (N)	13314	16189	2875	21.59%

Table 27: IP Study Injury Value Comparisons

IP Study (Baseline / Final IP Config)				
	Baseline	IP Redesign	Delta	% Change from Baseline
HIC 15	484	580	96	19.83%
Chest Resultant (g)	61	74	13	21.31%
Chest Deflect (mm)	66	51	-15	-22.73%
Neck Fx (N)	1550	1501	-49	-3.16%
Neck Fz (N)	4216	3832	-384	-9.11%
Neck My (N-M)	172	127	-45	-26.16%
Pelvis Resultant (g)	71	123	52	73.24%
Femur Loads (N) Ave L&R	Not collected	6567		

Conclusion

In an attempt to replicate a surrogate IP, more optimization could occur to further reduce injury, but that effort was not within the scope of this testing. When properly designed, the IP has the potential to redistribute that load across the surface and reduce the burden on the restraint system. Femurs allow for the distribution of some occupant injury. The implementation of the impact surface caused the head acceleration to increase, chest displacement to decrease, and pelvis acceleration to increase.

Chapter 6

Future System Level Design and System Level Testing Considerations for Military Vehicles

Sled Testing

This study evaluated various non pyrotechnic, pyrotechnic, and fixed restraint system combinations on a fixed steel seat (ECE R16). The TARDEC specified frontal pulse provides a high input into the restraint system. As such, the restraints need to be part of a complete energy absorbing systems and cannot mitigate injury alone. Pyrotechnic restraint systems provide promise, however, a sensor suite that can work for crash, blast, and rollover will have to be developed. Without initiating the pyrotechnics, the system provides no benefit. The current system design for OCP TECD (4 retractors + fixed crotch) provides optimal performance, with further tuning of interaction surfaces these numbers will improve. The restraint system must be validated with a designed/intended seat. Once a seat is available to test, further reductions in ATD injury numbers may be observed by providing additional energy absorption paths/mechanism (foam, deforming steel, etc.). When the feet were placed on a plane that replicated the original footrest, the IARV values for the neck were exceeded; keeping the legs on a lower plane resulted in a drop in these numbers.

Impact Surfaces

Certification in the automotive field requires that an entire vehicle is crash tested and the safety system is evaluated as a whole. In these tests, it is not unusual for the occupants to strike surfaces, such as the dashboard (also known as the IP or cockpit module). Initially, an automotive manufacturer runs crash tests on prototype vehicles to determine the crash pulse / deceleration experienced by a crash. This pulse is then taken and programmed into a servo hydraulic or pneumatic sled thus ensuring that the crash pulse can be replicated within the lab. Finally, a vehicle Body-In-White structure is taken and modified to reinforce it to allow for repeated usage on the sled.

Given that resources to crash and certify an entire system may be limited, decisions to test representative systems may be the only option. To accomplish this goal, it is crucial to utilize a representative pulse, representative impact surface, seating system, and safety systems. The focus on replicating an impact and surrounding surface, that provides energy absorption and is equivalent in dimension to that of an actual vehicle is important. During the course of OCP TECD, the restraints team replicated the surface of an existing military vehicle to replicate a real world scenario.

Sled testing utilizing this surrogate surface yielded test results that allowed for a reduction in ATD injury numbers. These results included a reduction in NIJ, an increase in femur loads, a reduction in neck tensile and shear forces, a reduction in neck moment, an increase in chest forces among other values that are evident in the Injury Categories reported earlier in the report. The occupant kinematics were changed with the introduction of the impact surface. The non-optimized surface provided a deceleration of the occupant, however not all of the injury numbers in other areas were within acceptable limits. During the development of this type of system, a cycle of testing, modification of the surface, and retesting were required to best tune the safety performance.

Sled Pulses

A holistic vehicle development phase required testing and retesting as necessary utilizing sled testing. In addition, collection of a proper sled pulse(s) from an actual vehicle is important to allow for the proper development of the entire safety system. To best accommodate this type of data collection, it would be necessary to have prototype vehicles built and tested in the frontal, side, rear, roll-over, and blast scenarios. During the OCP TECD, development of the frontal crash pulses was not collected in this fashion. They were instead created and modified to be what was believed to be accurate without final validation because the OCP TECD vehicle was never crashed.

Conclusions

Before this program was begun, many factors concerning occupant protection in military vehicles were not considered or were unknown. A defined gear set to use for testing, an accelerative pulse, restraint system routing, and restraint design best practices were either unavailable or were dictated by vehicle specific requirements. Understanding the overall implications and importance that restraints play in Soldier protection, a design and evaluation process for all military vehicle platforms was created.

The first factor to designing a restraint system for military vehicles is to design a system that Soldiers will utilize. When Soldiers were given the opportunity to provide feedback, the restraint system could be optimized to provide not only occupant protection but also comfort and usability. Soldiers who wore their restraints were more likely to survive blast, crash, and roll over scenarios than Soldiers who did not wear their restraints[4]. Therefore, designing an optimized restraint for Soldier's use can result in higher usage and decreased fatalities.

In the restraint system design and evaluation phase, various restraint system types were evaluated to determine the system that Soldiers most preferred. These evaluations began with the simplest of restraint types, that being of a manual adjustment restraint. The manual adjust restraint systems allowed occupants to adjust the restraint system as taut or loose as they choose. Ensuring that the restraint system was taut for all events could not be controlled. In addition, based on restraint evaluations, Soldiers were less likely to use manual adjust restraint systems due to discomfort.

Moving further into the restraint system evaluation, restraints with retractors were considered. The systems containing retractors would retract the webbing back into the restraint system when not in use. This provided for an opportunity for Soldiers to sit in the seat without having to move the restraints. However, this design had an issue associated with it. When the Soldier would sit and try to grab the restraints, they would often encounter problems because the restraints were difficult to access (for both manually and automatically retracting belts). It was only when restraint systems containing presenters on both the shoulder and lap restraints were introduced that the issue could be resolved. This restraint system containing the presenters was the most preferred system by most of the Soldiers. In addition, the Soldiers noted that ingress was made easier by this design and the restraints were readily accessible once seated. Based on the evaluations, the Soldiers preferred and felt more comfortable with the ReadyReach presenters vs. the sleeved presenters, so it was recommended that ReadyReach presenters on both the shoulder and the lap restraints be considered for future designs.

Upon completion of the restraint system evaluation, an ideal restraint system design was down-selected and created. The restraint Contractor developed the design and confirmed that it would fit the seat that was utilized for the program at the time. The design ensured that each DHM could be accounted for in all of the Soldier PPE configurations and Soldier sizes ranging from the smallest female to the largest male. Upon further review and approval, the system was sent into prototype production and was made available for evaluation.

The down selected restraint system was then evaluated on a servo-hydraulic sled. A simulated seated environment was created and a 50th percentile ATD with the Saw Gunner PPE was evaluated. As the ATD was placed on the sled, the restraints were routed over the PPE. At the time, the restraint routing was determined by the test engineer or technician. No particular steps were taken other than ensuring that the webbing was not crossed and that each end was properly buckled. During the initial test, the webbing slipped under the PPE and caused a test anomaly. The restraints under load travelled into the spaces of the PPE, causing a delayed coupling effect that added to forward excursion and occupant injury. The anomaly also resulted in damage to the PPE and caused it to separate from the ATD. Because of this anomaly, a restraint placement procedure was created. Upon placing the webbing under the pouches located at the belt line of the ATD, a loss in restraint was no longer observed.

Once all anomalies were corrected on the sled, a systematic evaluation of the restraint system was conducted. The series provided information that TARDEC previously did not have. It was determined that the combination of the ATD and PPE weight coupled to an aggressive, sustained pulse could generate forces higher than are typically designed by restraint manufactures. Furthermore seat designs in terms of rigidity, seat recline angles, seat pan angles, seat friction, and surrounding impact surfaces also may influence occupant injury and should be considered in the design of the vehicle.

The results of this study revealed that encumbrance can become damaged and load anomalies may exist when restraints are routed improperly. Higher chest displacements are encountered when encumbrance is used, with the encumbrance causing the neck to extend as the head rotates forward.

Pulses that are less aggressive cause timing of the injuries to shift and have lower magnitudes. Pulses do not appear to have an effect on neck and chest reactions with an encumbered occupant. Restraint loads appear to increase, as the crash pulse is made more aggressive.

The evaluations of the restraint system initially did not consist of an impact surface, such as an IP. TARDEC determined that an evaluation with an impact surface should be considered. Working with the Contractor, a surface was created that resembled a production military vehicle. In an attempt to replicate a surrogate IP, more optimization such as panel contouring, seating, and restraint tuning could reduce injury further. It was determined that the IP redistributes loads across the surface and reduces the burden on the restraint system. By absorbing energy, the femurs allow for the distribution of some occupant injury, with increases in femur loads allowing for decreases in other measured injury values.

Further implementation and hardening of the system (creating the severe duty sealed retractor) resulted in a robust system that is capable of handling environmental effects and still continues to function, providing the occupant with the most reliable restraint system possible. The tie in with ReadyReach has further lessened the burden on Soldiers and allows for restraints to be available the moment the Soldiers sit down. With the ease of this operation, Soldiers are more likely to utilize this system and encourage others to do the same.

In July 2015 and November 2015, final blast confirmation tests were conducted. The restraint system designed for the program did not exhibit any test anomalies and was found to properly restraint the ATD.

Recommendations

TARDEC should continue development of restraint systems in line with seat vendors. Having the restraints designed with adequate mounting locations and webbing lengths in mind is important. As sensing systems mature, the potential for utilization of pyrotechnic systems, such as airbags and advanced restraints, becomes possible. With military vehicle programs moving into new developments, RESETs and RECAPs, moving safety development forward and implementing it with performance tuning of the impact surfaces and crush structures is necessary. The localized environment around the occupant plays a significant role in the outcome of test results. Seat designs in terms of rigidity, seat recline angles, seat pan angles, seat friction, and surrounding impact surfaces influence occupant injury and should be considered in the future design of military vehicles. In an attempt to replicate a surrogate IP, it was clear that more optimization must occur to reduce injury further. A distributed focus on blast, crash, and roll-overs will provide Soldiers with the best possible protection.

Future Work

Follow on work should consist of further development of an optimized restraint system. Pyrotechnic systems with integrated restraint air bags and load limiting will be utilized for the optimization. These systems will take Soldier's gear into account and provide for a suite of blast, crash, and roll-over event protection. Furthermore, the system will be packaged within an energy absorbing seat that will have the ability to be integrated onto various military vehicle platforms.

Pyrotechnic restraint systems will have the capability of restraining the occupant during blast, crash, roll-over, and other injury causing events. A sensing strategy could activate the Pyrotechnic system during the initial blast loading into the seat (slack in the Restraint System is created when the occupant starts loading the seat in a blast). This system does not exist currently and prevents the implementation of this type of system.

Load limiting features in the restraint system design were not evaluated in this study to limit experimental variation. The elimination of load limiting features was intended to reduce the available displacement of the gear. If load limiting had been utilized and tuned properly in the shoulder restraints, it is possible that the encumbrance will have moved further. This movement could likely lower forces in both the chest and the neck. Furthermore, the localized environment around the occupant can play a significant role in the outcome of the sled test results and occupant injury levels. Both considerations are topics for future study.

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Appendices

Appendix A: Demographics and Background Survey

DEMOGRAPHICS AND BACKGROUND Participant #________

The Occupant Centric Platform Technology Enabled Capability Demonstration Program (OCP TECD) is testing new seat restraints. By completing this evaluation you will be providing valuable information to Army designers so that the Army may better serve your needs. *Please fill out this questionnaire as completely as you can.*

All individual responses will be kept confidential, only summaries of all data will be reported.

Demographics:

Rank:___ MOS: _____ Age:______

Height:_______ Weight:_____ Gender: ( ) Male ( ) Female

How long have you been in the Army? _____ years _____months

Status: ( ) Active ( ) Reserve ( ) Guard

Deployment:

Have you been deployed? ( ) Yes ( ) No

If YES, where: ____

Dates of last deployment: From _______________(month/year) to _______________(month/year)

Position:

Please circle the option that best describes your *current* position

Driver/Vehicle Crewman	SAW Gunner
Squad Leader	M240B Gunner
Fire Team Leader	M240 AG
Rifleman	Combat Medic
Grenadier	Other ____________________

Please circle the option that best describes your position when you were *deployed*

Driver/Vehicle Crewman	SAW Gunner
Squad Leader	M240B Gunner
Fire Team Leader	M240 AG
Rifleman	Combat Medic
Grenadier	Other ____________________

What class of vehicles do you have experience with? Please circle all that apply:

Transport, cargo
Driver Occupant/other

Engineering Equipment
Driver Occupant/other

Wheeled Combat Vehicle
Driver Occupant/other

Tracked Combat Vehicle
Driver Occupant/other

When deployed overseas did you typically wear your seat belt in military vehicles? ( ) Yes ( ) No

If you answered NO to wearing a seat belt, please explain why:

____

____

Did you have any problems with the design or functionality of the seat belts in your military vehicle?

( ) Yes ( ) No

If you answered YES, were any modifications (loosen or cut straps, etc.) made so the seat belts could be worn?

Please explain:

____

____

____

What vehicle incidents have you been involved in? Please circle all that apply:

Crash

Rollover

IED, mine

RPG, kinetic/ballistic

None

Appendix B: Seat Restraint Survey Document

All pages were identical except for the seat restraint system. Sample pages included here

Ground Vehicle Restraint User Feedback Survey Participant #________

EXAMPLE: Seat 1A: Steel cable mounted AMSAFE rotary buckle

Please rate each of the following tasks using the appropriate scale, circling *one* number for each task. If you did not perform a particular task, circle N/A for Not Applicable

1) ***Belt* Accessibility:**

(1) Very difficult to find and grab belts
(2) Moderately difficult to find and grab belts
(3) Acceptable
(4) Moderately easy to find and grab belts
(5) Very easy to find and grab belts
(N/A)

2) ***Buckle* Accessibility:**

(1) Very difficult to find and grab buckle
(2) Moderately difficult to find and grab buckle
(3) Acceptable
(4) Moderately easy to find and grab buckle
(5) Very easy to find and grab buckle
(N/A)

3) **Egress:**

(1) No confidence I could get out at all
(2) Some issues getting out
(3) Acceptable
(4) Confident I could get out
(5) Very confident I would get out all the time
(N/A)

4) **Entanglement: Did you experience…**

(1) Extreme hang-ups
(2) Minor hang-up
(3) No hang-ups
(N/A)

5) **Overall ease of Operation:**

(1) Very difficult
(2) Somewhat difficult
(3) Acceptable
(4) Somewhat easy
(5) Very easy
(N/A)

6) **Comfort of Restraint System:**

(1) Very uncomfortable
(2) Moderately uncomfortable
(3) Acceptable
(4) Moderately comfortable
(5) Very comfortable
(N/A)

7) **In theater, I would use this restraint…:**

(1) Never
(2) Only if I had to
(3) Sometimes
(4) Probably
(5) Always
(N/A)

8) **My ideal restraint fit is…**

(1) Loose
(2) Snug
(3) Tight
(N/A)

Do you like this restraint system? ( ) Yes ( ) No

Would you use this restraint system? ( ) Yes ( ) No

If you provided a rating of ***3 or below*** for questions 1-7 (or 2 or below for question 4) please explain why:

____

____

2. Please list any other comments you have on the seat restraints:

____

____

____

____

Appendix C: Exit Interview Document

Exit Interview

Participant #________

Which *retractor* style did you like the most? (*Choose one*)

( ) Manual adjustment
( ) Shoulder retractors only
( ) Lap retractors only
( ) Both shoulder and lap retractors
( ) Shoulder, lap and buckle retractors

Which *strap* style did you like the most? (*Choose one*)

( ) Shoulder presenters only
( ) Lap presenters only
( ) Both shoulder and lap presenters
( ) Ready reach (loop straps)

Please rate your level of satisfaction with each restraint component based off the following scale. *Please circle only one*. If you have no basis with, which to form an opinion, choose N/A for Not Applicable.

Very Unacceptable	Moderately Unacceptable	Neither Acceptable nor Unacceptable	Moderately Acceptable	Very Acceptable
1	2	3	4	5

Steel cable mounted buckle	N/A	1	2	3	4	5
Shoulder belt release (pilot)	N/A	1	2	3	4	5
Plain rotary buckle	N/A	1	2	3	4	5
Rotary buckle with thumb release	N/A	1	2	3	4	5
Lift tab release/channel tongue	N/A	1	2	3	4	5
Reduced dexterity (butterfly)	N/A	1	2	3	4	5
Slide through shoulder tongues	N/A	1	2	3	4	5
Motorized pre-tensioner	N/A	1	2	3	4	5
Over-the-shoulder bar	N/A	1	2	3	4	5

What do you want to see in a restraint system that would make you wear it all the time?
____
____
____
____

Please provide a personal anecdote or experience with seat restraints:

____

____

DEMOGRAPHICS AND BACKGROUND

Participant #________

The Occupant Centric Platform Technology Enabled Capability Demonstration Program (OCP TECD) is testing new seat restraints. By completing this evaluation you will be providing valuable information to Army designers so that the Army may better serve your needs. *Please fill out this questionnaire as completely as you can.*

All individual responses will be kept confidential, only summaries of all data will be reported.

Demographics:

Rank:___ MOS: ______ Age:_______

Height:_______ Weight:______ Gender: ( ) Male ( ) Female

How long have you been in the Army? _____ years _____months

Status: ( ) Active ( ) Reserve ( ) Guard

Deployment:

Have you been deployed? ( ) Yes ( ) No

If YES, where:

____

Dates of last deployment: From _______________(month/year) to __________(month/year)

Position:

Please mark the option that best describes your *current* position

( ) Driver/Vehicle Crewman
( ) Squad Leader
( ) Fire Team Leader
( ) Rifleman
( ) Grenadier
( ) SAW Gunner
( ) M240B Gunner
( ) M240 AG
( ) Combat Medic
( ) Other ____________________

Please mark the option that best describes your position when you were *deployed*

( ) Driver/Vehicle Crewman
( ) Squad Leader
( ) Fire Team Leader
( ) Rifleman
( ) Grenadier
( ) SAW Gunner
( ) M240B Gunner
( ) M240 AG
( ) Combat Medic
( ) Other ____________________

What class of vehicles do you have experience with? Please mark all that apply:

Transport, Cargo

( ) Driver ( ) Occupant/other

Engineering Equipment

( ) Driver ( ) Occupant/other

Wheeled Combat Vehicle

( ) Driver ( ) Occupant/other

Tracked Combat Vehicle

( ) Driver ( ) Occupant/other

When deployed overseas did you typically wear your seat belt in military vehicles?
( ) Yes ( ) No

If you answered NO to wearing a seat belt, please explain why:

____

____

____

____

Did you have any problems with the design or functionality of the seat belts in your military vehicle? ( ) Yes ( ) No

If you answered YES, were any modifications (loosen or cut straps, etc.) made so the seat belts could be worn?

Please explain:

____

____

____

What vehicle incidents have you been involved in? Please mark all that apply:

( ) Crash

( ) Rollover

( ) IED, mine

( ) RPG, kinetic/ballistic

( ) None

Appendix E Seat Restraint Survey Document

Ground Vehicle Restraint User Feedback Survey

Participant #________

Rotary buckle with 4-point retractors with fixed 5th point featuring ReadyReach presenters

Please rate each of the following tasks using the appropriate scale, circling *one* number for each task. If you did not perform a particular task, circle N/A for Not Applicable

1) ***Belt*** **Accessibility:**

(1) Very difficult to find and grab belts
(2) Moderately difficult to find and grab belts
(3) Acceptable
(4) Moderately easy to find and grab belts
(5) Very easy to find and grab belts
(N/A)

2) ***Buckle*** **Accessibility:**

(1) Very difficult to find and grab buckle
(2) Moderately difficult to find and grab buckle
(3) Acceptable
(4) Moderately easy to find and grab buckle
(5) Very easy to find and grab buckle
(N/A)

3) **Egress:**

(1) No confidence I could get out at all
(2) Some issues getting out
(3) Acceptable
(4) Confident I could get out
(5) Very confident I would get out all the time
(N/A)

4) **Entanglement: Did you experience…**

(1) Extreme hang-ups
(2) Minor hang-up
(3) No hang-ups
(N/A)

5) **Overall ease of Operation:**

(1) Very difficult
(2) Somewhat difficult
(3) Acceptable
(4) Somewhat easy
(5) Very easy
(N/A)

6) **Comfort of Restraint System:**

(1) Very uncomfortable
(2) Moderately uncomfortable
(3) Acceptable
(4) Moderately comfortable
(5) Very comfortable
(N/A)

7)

In theater, I would use this restraint…:

(1) Never
(2) Only if I had to
(3) Sometimes
(4) Probably
(5) Always
(N/A)

8)

My ideal restraint fit is…

(1) Loose
(2) Snug
(3) Tight
(N/A)

Do you like this restraint system? ( ) Yes ( ) No

Would you use this restraint system? ( ) Yes ( ) No

If you provided a rating of ***3 or below*** for questions 1-7 (or 2 or below for question 4) please explain why:

____

____

____

2. Please list any other comments you have on the seat restraints:

____

____

____

Appendix F Exit Interview Document

Exit Interview

Participant #________

What *restraint* style do you like the most?
(*Choose one)*

( ) Manual adjustment
( ) Shoulder retractors only
( ) Lap retractors only
( ) Both shoulder and lap retractors
( ) Shoulder, lap and buckle retractors

Which *strap* style would you like the most?
(*Choose one)*

( ) Shoulder presenters only
( ) Lap presenters only
( ) Both shoulder and lap presenters

Please rate your level of satisfaction with the restraint component based off the following scale. *Please circle only one*. If you have no basis with, which to form an opinion, choose N/A for Not Applicable.

Very Unacceptable	Moderately Unacceptable	Neither Acceptable nor Unacceptable	Moderately Acceptable	Very Acceptable
1	2	3	4	5

ReadyReach System	N/A	1	2	3	4	5
Retractors	N/A	1	2	3	4	5
Fixed Restraints	N/A	1	2	3	4	5

What do you want to see in a restraint system that would make you wear it all the time?

____
____
____
____

Please provide a personal anecdote or experience with seat restraints:

____
____
____
____

Appendix G SPSS Output Data

```
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  /WSFACTOR=Seat 10 Polynomial
  /METHOD=SSTYPE(3)
  /EMMEANS=TABLES(Seat) COMPARE ADJ(BONFERRONI)
  /PRINT=DESCRIPTIVE ETASQ
  /CRITERIA=ALPHA(.05)
  /WSDESIGN=Seat.
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General Linear Model

Notes

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	Cases Used	Statistics are based on all cases with valid data for all variables in the model.
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[DataSet0]

Page 1

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Within-Subjects Factors

Measure: MEASURE_1

Seat	Dependent Variable
1	A1
2	B1
3	C1
4	D1
5	E1
6	F1
7	G1
8	H1
9	I1
10	J1

Descriptive Statistics

	Mean	Std. Deviation	N
A1	3.4118	1.32565	17
B1	3.5294	1.28051	17
C1	2.8824	1.40900	17
D1	3.7059	1.21268	17
E1	3.7647	1.25147	17
F1	3.9412	.96635	17
G1	3.7059	1.49016	17
H1	4.5294	.79982	17
I1	4.4118	.61835	17
J1	4.5882	.87026	17

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Seat	Pillai's Trace	.659	1.720[b]	9.000	8.000	.228	.659
	Wilks' Lambda	.341	1.720[b]	9.000	8.000	.228	.659
	Hotelling's Trace	1.935	1.720[b]	9.000	8.000	.228	.659
	Roy's Largest Root	1.935	1.720[b]	9.000	8.000	.228	.659

a. Design: Intercept
Within Subjects Design: Seat

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Seat	.008	62.347	44	.050	.538	.799	.111

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Seat

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Seat	Sphericity Assumed	44.376	9	4.931	5.616	.000	.260
	Greenhouse-Geisser	44.376	4.839	9.170	5.616	.000	.260
	Huynh-Feldt	44.376	7.192	6.171	5.616	.000	.260
	Lower-bound	44.376	1.000	44.376	5.616	.031	.260
Error(Seat)	Sphericity Assumed	126.424	144	.878			
	Greenhouse-Geisser	126.424	77.426	1.633			
	Huynh-Feldt	126.424	115.067	1.099			
	Lower-bound	126.424	16.000	7.901			

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Seat	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Seat	Linear	32.653	1	32.653	20.378	.000	.560
	Quadratic	1.499	1	1.499	2.743	.117	.146
	Cubic	1.022	1	1.022	1.620	.221	.092
	Order 4	.107	1	.107	.110	.744	.007
	Order 5	.146	1	.146	.173	.683	.011
	Order 6	1.059	1	1.059	1.241	.282	.072
	Order 7	5.931	1	5.931	7.645	.014	.323
	Order 8	.006	1	.006	.010	.921	.001
	Order 9	1.954	1	1.954	1.769	.202	.100
Error(Seat)	Linear	25.638	16	1.602			
	Quadratic	8.743	16	.546			
	Cubic	10.086	16	.630			
	Order 4	15.449	16	.966			
	Order 5	13.485	16	.843			
	Order 6	13.649	16	.853			
	Order 7	12.412	16	.776			
	Order 8	9.289	16	.581			
	Order 9	17.673	16	1.105			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	2515.976	1	2515.976	461.523	.000	.966
Error	87.224	16	5.451			

Estimated Marginal Means

Seat

Estimates

Measure: MEASURE_1

Seat	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	3.412	.322	2.730	4.093
2	3.529	.311	2.871	4.188
3	2.882	.342	2.158	3.607
4	3.706	.294	3.082	4.329
5	3.765	.304	3.121	4.408
6	3.941	.234	3.444	4.438
7	3.706	.361	2.940	4.472
8	4.529	.194	4.118	4.941
9	4.412	.150	4.094	4.730
10	4.588	.211	4.141	5.036

Pairwise Comparisons

Measure: MEASURE_1

(I) Seat	(J) Seat	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	2	-.118	.169	1.000	-.788	.552
	3	.529	.333	1.000	-.793	1.851
	4	-.294	.318	1.000	-1.555	.967
	5	-.353	.331	1.000	-1.667	.961
	6	-.529	.311	1.000	-1.761	.702
	7	-.294	.294	1.000	-1.460	.872
	8	-1.118	.342	.216	-2.473	.237
	9	-1.000	.332	.373	-2.317	.317
	10	-1.176	.324	.100	-2.459	.106
2	1	.118	.169	1.000	-.552	.788
	3	.647	.353	1.000	-.752	2.046
	4	-.176	.312	1.000	-1.413	1.060
	5	-.235	.315	1.000	-1.486	1.015
	6	-.412	.298	1.000	-1.592	.769
	7	-.176	.231	1.000	-1.091	.738
	8	-1.000	.309	.233	-2.226	.226
	9	-.882	.308	.503	-2.103	.338
	10	-1.059	.315	.178	-2.307	.189
3	1	-.529	.333	1.000	-1.851	.793
	2	-.647	.353	1.000	-2.046	.752
	4	-.824	.422	1.000	-2.497	.850
	5	-.882	.461	1.000	-2.710	.945
	6	-1.059	.406	.862	-2.670	.553
	7	-.824	.346	1.000	-2.193	.546
	8	-1.647*	.363	.015	-3.087	-.207
	9	-1.529*	.375	.039	-3.016	-.043
	10	-1.706*	.391	.022	-3.255	-.157
4	1	.294	.318	1.000	-.967	1.555
	2	.176	.312	1.000	-1.060	1.413
	3	.824	.422	1.000	-.850	2.497
	5	-.059	.264	1.000	-1.105	.987
	6	-.235	.250	1.000	-1.228	.758
	7	.000	.411	1.000	-1.631	1.631
	8	-.824	.366	1.000	-2.275	.628
	9	-.706	.281	1.000	-1.821	.410
	10	-.882	.283	.297	-2.004	.239
5	1	.353	.331	1.000	-.961	1.667
	2	.235	.315	1.000	-1.015	1.486
	3	.882	.461	1.000	-.945	2.710
	4	.059	.264	1.000	-.987	1.105
	6	-.176	.287	1.000	-1.316	.963
	7	.059	.337	1.000	-1.278	1.396
	8	-.765	.389	1.000	-2.305	.776
	9	-.647	.270	1.000	-1.719	.425
	10	-.824	.287	.505	-1.963	.316

Pairwise Comparisons

Measure: MEASURE_1

(I) Seat	(J) Seat	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
6	1	.529	.311	1.000	-.702	1.761
	2	.412	.298	1.000	-.769	1.592
	3	1.059	.406	.862	-.553	2.670
	4	.235	.250	1.000	-.758	1.228
	5	.176	.287	1.000	-.963	1.316
	7	.235	.379	1.000	-1.267	1.738
	8	-.588	.310	1.000	-1.817	.640
	9	-.471	.244	1.000	-1.439	.498
	10	-.647	.242	.743	-1.605	.311
7	1	.294	.294	1.000	-.872	1.460
	2	.176	.231	1.000	-.738	1.091
	3	.824	.346	1.000	-.546	2.193
	4	.000	.411	1.000	-1.631	1.631
	5	-.059	.337	1.000	-1.396	1.278
	6	-.235	.379	1.000	-1.738	1.267
	8	-.824	.346	1.000	-2.193	.546
	9	-.706	.340	1.000	-2.056	.644
	10	-.882	.352	1.000	-2.279	.515
8	1	1.118	.342	.216	-.237	2.473
	2	1.000	.309	.233	-.226	2.226
	3	1.647*	.363	.015	.207	3.087
	4	.824	.366	1.000	-.628	2.275
	5	.765	.389	1.000	-.776	2.305
	6	.588	.310	1.000	-.640	1.817
	7	.824	.346	1.000	-.546	2.193
	9	.118	.169	1.000	-.552	.788
	10	-.059	.234	1.000	-.988	.870
9	1	1.000	.332	.373	-.317	2.317
	2	.882	.308	.503	-.338	2.103
	3	1.529*	.375	.039	.043	3.016
	4	.706	.281	1.000	-.410	1.821
	5	.647	.270	1.000	-.425	1.719
	6	.471	.244	1.000	-.498	1.439
	7	.706	.340	1.000	-.644	2.056
	8	-.118	.169	1.000	-.788	.552
	10	-.176	.176	1.000	-.876	.523
10	1	1.176	.324	.100	-.106	2.459
	2	1.059	.315	.178	-.189	2.307
	3	1.706*	.391	.022	.157	3.255
	4	.882	.283	.297	-.239	2.004
	5	.824	.287	.505	-.316	1.963
	6	.647	.242	.743	-.311	1.605
	7	.882	.352	1.000	-.515	2.279
	8	.059	.234	1.000	-.870	.988
	9	.176	.176	1.000	-.523	.876

Based on estimated marginal means

*. The mean difference is significant at the

b. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	.659	1.720[a]	9.000	8.000	.228	.659
Wilks' lambda	.341	1.720[a]	9.000	8.000	.228	.659
Hotelling's trace	1.935	1.720[a]	9.000	8.000	.228	.659
Roy's largest root	1.935	1.720[a]	9.000	8.000	.228	.659

Each F tests the multivariate effect of Seat. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

```
GLM A2 B2 C2 D2 E2 F2 G2 H2 I2 J2
 /WSFACTOR=Seat 10 Polynomial
 /METHOD=SSTYPE(3)
 /EMMEANS=TABLES(Seat) COMPARE ADJ(BONFERRONI)
 /PRINT=DESCRIPTIVE ETASQ
 /CRITERIA=ALPHA(.05)
 /WSDESIGN=Seat.
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General Linear Model

Notes

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[DataSet0]

Within-Subjects Factors

Measure: MEASURE_1

Seat	Dependent Variable
1	A2
2	B2
3	C2
4	D2
5	E2
6	F2
7	G2
8	H2
9	I2
10	J2

Descriptive Statistics

	Mean	Std. Deviation	N
A2	3.8125	1.16726	16
B2	3.8125	1.16726	16
C2	3.0625	1.52616	16
D2	3.8125	1.27639	16
E2	4.2500	.85635	16
F2	4.0000	.89443	16
G2	3.7500	1.34164	16
H2	4.5625	.72744	16
I2	4.1250	1.14746	16
J2	4.5000	.81650	16

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Seat	Pillai's Trace	.778	2.733[b]	9.000	7.000	.099	.778
	Wilks' Lambda	.222	2.733[b]	9.000	7.000	.099	.778
	Hotelling's Trace	3.514	2.733[b]	9.000	7.000	.099	.778
	Roy's Largest Root	3.514	2.733[b]	9.000	7.000	.099	.778

a. Design: Intercept
Within Subjects Design: Seat

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Seat	.001	77.574	44	.002	.558	.872	.111

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Seat

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Seat	Sphericity Assumed	26.906	9	2.990	4.693	.000	.238
	Greenhouse-Geisser	26.906	5.018	5.362	4.693	.001	.238
	Huynh-Feldt	26.906	7.844	3.430	4.693	.000	.238
	Lower-bound	26.906	1.000	26.906	4.693	.047	.238
Error(Seat)	Sphericity Assumed	85.994	135	.637			
	Greenhouse-Geisser	85.994	75.275	1.142			
	Huynh-Feldt	85.994	117.657	.731			
	Lower-bound	85.994	15.000	5.733			

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Seat	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Seat	Linear	11.555	1	11.555	11.358	.004	.431
	Quadratic	.720	1	.720	2.097	.168	.123
	Cubic	.992	1	.992	1.603	.225	.097
	Order 4	1.535	1	1.535	3.568	.078	.192
	Order 5	.018	1	.018	.023	.880	.002
	Order 6	1.105	1	1.105	1.700	.212	.102
	Order 7	10.313	1	10.313	15.361	.001	.506
	Order 8	.453	1	.453	.555	.468	.036
	Order 9	.216	1	.216	.517	.483	.033
Error(Seat)	Linear	15.260	15	1.017			
	Quadratic	5.151	15	.343			
	Cubic	9.280	15	.619			
	Order 4	6.451	15	.430			
	Order 5	11.524	15	.768			
	Order 6	9.747	15	.650			
	Order 7	10.070	15	.671			
	Order 8	12.238	15	.816			
	Order 9	6.271	15	.418			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	2520.156	1	2520.156	370.816	.000	.961
Error	101.944	15	6.796			

Estimated Marginal Means

Seat

Estimates

Measure: MEASURE_1

Seat	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	3.813	.292	3.191	4.434
2	3.813	.292	3.191	4.434
3	3.063	.382	2.249	3.876
4	3.813	.319	3.132	4.493
5	4.250	.214	3.794	4.706
6	4.000	.224	3.523	4.477
7	3.750	.335	3.035	4.465
8	4.563	.182	4.175	4.950
9	4.125	.287	3.514	4.736
10	4.500	.204	4.065	4.935

Pairwise Comparisons

Measure: MEASURE_1

(I) Seat	(J) Seat	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.000	.224	1.000	-.899	.899
	3	.750	.323	1.000	-.548	2.048
	4	.000	.289	1.000	-1.161	1.161
	5	-.438	.288	1.000	-1.596	.721
	6	-.188	.209	1.000	-1.026	.651
	7	.063	.347	1.000	-1.334	1.459
	8	-.750	.250	.404	-1.755	.255
	9	-.313	.285	1.000	-1.457	.832
	10	-.688	.313	1.000	-1.944	.569
2	1	.000	.224	1.000	-.899	.899
	3	.750	.310	1.000	-.495	1.995
	4	.000	.183	1.000	-.734	.734
	5	-.438	.258	1.000	-1.474	.599
	6	-.188	.188	1.000	-.941	.566
	7	.063	.213	1.000	-.796	.921
	8	-.750	.296	1.000	-1.939	.439
	9	-.313	.218	1.000	-1.190	.565
	10	-.688	.270	.998	-1.771	.396
3	1	-.750	.323	1.000	-2.048	.548
	2	-.750	.310	1.000	-1.995	.495
	4	-.750	.335	1.000	-2.099	.599
	5	-1.188	.390	.366	-2.754	.379
	6	-.938	.359	.885	-2.381	.506
	7	-.688	.338	1.000	-2.047	.672
	8	-1.500	.376	.054	-3.013	.013
	9	-1.063	.370	.528	-2.552	.427
	10	-1.438	.408	.138	-3.078	.203
4	1	.000	.289	1.000	-1.161	1.161
	2	.000	.183	1.000	-.734	.734
	3	.750	.335	1.000	-.599	2.099
	5	-.438	.241	1.000	-1.406	.531
	6	-.188	.209	1.000	-1.026	.651
	7	.063	.295	1.000	-1.125	1.250
	8	-.750	.323	1.000	-2.048	.548
	9	-.313	.198	1.000	-1.110	.485
	10	-.688	.285	1.000	-1.832	.457
5	1	.438	.288	1.000	-.721	1.596
	2	.438	.258	1.000	-.599	1.474
	3	1.188	.390	.366	-.379	2.754
	4	.438	.241	1.000	-.531	1.406
	6	.250	.250	1.000	-.755	1.255
	7	.500	.354	1.000	-.922	1.922
	8	-.313	.254	1.000	-1.332	.707
	9	.125	.155	1.000	-.497	.747
	10	-.250	.250	1.000	-1.255	.755

Pairwise Comparisons

Measure: MEASURE_1

(I) Seat	(J) Seat	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
6	1	.188	.209	1.000	-.651	1.026
	2	.188	.188	1.000	-.566	.941
	3	.938	.359	.885	-.506	2.381
	4	.188	.209	1.000	-.651	1.026
	5	-.250	.250	1.000	-1.255	.755
	7	.250	.233	1.000	-.686	1.186
	8	-.563	.182	.334	-1.294	.169
	9	-.125	.221	1.000	-1.015	.765
	10	-.500	.204	1.000	-1.321	.321
7	1	-.063	.347	1.000	-1.459	1.334
	2	-.063	.213	1.000	-.921	.796
	3	.688	.338	1.000	-.672	2.047
	4	-.063	.295	1.000	-1.250	1.125
	5	-.500	.354	1.000	-1.922	.922
	6	-.250	.233	1.000	-1.186	.686
	8	-.813	.332	1.000	-2.147	.522
	9	-.375	.287	1.000	-1.528	.778
	10	-.750	.296	1.000	-1.939	.439
8	1	.750	.250	.404	-.255	1.755
	2	.750	.296	1.000	-.439	1.939
	3	1.500	.376	.054	-.013	3.013
	4	.750	.323	1.000	-.548	2.048
	5	.313	.254	1.000	-.707	1.332
	6	.563	.182	.334	-.169	1.294
	7	.813	.332	1.000	-.522	2.147
	9	.438	.273	1.000	-.662	1.537
	10	.063	.249	1.000	-.941	1.066
9	1	.313	.285	1.000	-.832	1.457
	2	.313	.218	1.000	-.565	1.190
	3	1.063	.370	.528	-.427	2.552
	4	.313	.198	1.000	-.485	1.110
	5	-.125	.155	1.000	-.747	.497
	6	.125	.221	1.000	-.765	1.015
	7	.375	.287	1.000	-.778	1.528
	8	-.438	.273	1.000	-1.537	.662
	10	-.375	.272	1.000	-1.468	.718
10	1	.688	.313	1.000	-.569	1.944
	2	.688	.270	.998	-.396	1.771
	3	1.438	.408	.138	-.203	3.078
	4	.688	.285	1.000	-.457	1.832
	5	.250	.250	1.000	-.755	1.255
	6	.500	.204	1.000	-.321	1.321
	7	.750	.296	1.000	-.439	1.939
	8	-.063	.249	1.000	-1.066	.941
	9	.375	.272	1.000	-.718	1.468

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	.778	2.733[a]	9.000	7.000	.099	.778
Wilks' lambda	.222	2.733[a]	9.000	7.000	.099	.778
Hotelling's trace	3.514	2.733[a]	9.000	7.000	.099	.778
Roy's largest root	3.514	2.733[a]	9.000	7.000	.099	.778

Each F tests the multivariate effect of Seat. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

```
GLM A3 B3 C3 D3 E3 F3 G3 H3 I3 J3
 /WSFACTOR=Seat 10 Polynomial
 /METHOD=SSTYPE(3)
 /EMMEANS=TABLES(Seat) COMPARE ADJ(BONFERRONI)
 /PRINT=DESCRIPTIVE ETASQ
 /CRITERIA=ALPHA(.05)
 /WSDESIGN=Seat.
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General Linear Model

Notes

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[DataSet0]

Within-Subjects Factors

Measure: MEASURE_1

Seat	Dependent Variable
1	A3
2	B3
3	C3
4	D3
5	E3
6	F3
7	G3
8	H3
9	I3
10	J3

Descriptive Statistics

	Mean	Std. Deviation	N
A3	3.2500	1.06992	20
B3	4.0000	1.29777	20
C3	3.5500	1.27630	20
D3	3.8000	1.10501	20
E3	4.0000	.97333	20
F3	4.2000	.89443	20
G3	3.8000	1.32188	20
H3	4.3000	.86450	20
I3	4.2000	1.00525	20
J3	3.8000	1.28145	20

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Seat	Pillai's Trace	.721	3.152[b]	9.000	11.000	.038	.721
	Wilks' Lambda	.279	3.152[b]	9.000	11.000	.038	.721
	Hotelling's Trace	2.579	3.152[b]	9.000	11.000	.038	.721
	Roy's Largest Root	2.579	3.152[b]	9.000	11.000	.038	.721

a. Design: Intercept
Within Subjects Design: Seat

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Seat	.011	71.459	44	.008	.521	.713	.111

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Seat

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Seat	Sphericity Assumed	18.680	9	2.076	2.975	.003	.135
	Greenhouse-Geisser	18.680	4.691	3.982	2.975	.018	.135
	Huynh-Feldt	18.680	6.418	2.911	2.975	.008	.135
	Lower-bound	18.680	1.000	18.680	2.975	.101	.135
Error(Seat)	Sphericity Assumed	119.320	171	.698			
	Greenhouse-Geisser	119.320	89.138	1.339			
	Huynh-Feldt	119.320	121.939	.979			
	Lower-bound	119.320	19.000	6.280			

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Seat	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Seat	Linear	6.430	1	6.430	9.983	.005	.344
	Quadratic	3.419	1	3.419	4.900	.039	.205
	Cubic	.163	1	.163	.177	.679	.009
	Order 4	1.915	1	1.915	4.036	.059	.175
	Order 5	.154	1	.154	.103	.751	.005
	Order 6	3.373	1	3.373	4.199	.055	.181
	Order 7	1.636	1	1.636	4.662	.044	.197
	Order 8	.523	1	.523	1.374	.256	.067
	Order 9	1.068	1	1.068	2.055	.168	.098
Error(Seat)	Linear	12.237	19	.644			
	Quadratic	13.256	19	.698			
	Cubic	17.488	19	.920			
	Order 4	9.016	19	.475			
	Order 5	28.283	19	1.489			
	Order 6	15.262	19	.803			
	Order 7	6.668	19	.351			
	Order 8	7.236	19	.381			
	Order 9	9.874	19	.520			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	3026.420	1	3026.420	480.866	.000	.962
Error	119.580	19	6.294			

Estimated Marginal Means

Seat

Estimates

Measure: MEASURE_1

Seat	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	3.250	.239	2.749	3.751
2	4.000	.290	3.393	4.607
3	3.550	.285	2.953	4.147
4	3.800	.247	3.283	4.317
5	4.000	.218	3.544	4.456
6	4.200	.200	3.781	4.619
7	3.800	.296	3.181	4.419
8	4.300	.193	3.895	4.705
9	4.200	.225	3.730	4.670
10	3.800	.287	3.200	4.400

Pairwise Comparisons

Measure: MEASURE_1

(I) Seat	(J) Seat	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-.750	.250	.331	-1.709	.209
	3	-.300	.291	1.000	-1.417	.817
	4	-.550	.246	1.000	-1.493	.393
	5	-.750	.280	.666	-1.824	.324
	6	-.950*	.235	.031	-1.851	-.049
	7	-.550	.266	1.000	-1.572	.472
	8	-1.050*	.223	.007	-1.907	-.193
	9	-.950	.256	.067	-1.933	.033
	10	-.550	.276	1.000	-1.609	.509
2	1	.750	.250	.331	-.209	1.709
	3	.450	.285	1.000	-.645	1.545
	4	.200	.287	1.000	-.900	1.300
	5	.000	.340	1.000	-1.306	1.306
	6	-.200	.268	1.000	-1.227	.827
	7	.200	.213	1.000	-.616	1.016
	8	-.300	.252	1.000	-1.268	.668
	9	-.200	.277	1.000	-1.264	.864
	10	.200	.186	1.000	-.515	.915
3	1	.300	.291	1.000	-.817	1.417
	2	-.450	.285	1.000	-1.545	.645
	4	-.250	.260	1.000	-1.249	.749
	5	-.450	.344	1.000	-1.770	.870
	6	-.650	.350	1.000	-1.993	.693
	7	-.250	.347	1.000	-1.581	1.081
	8	-.750	.260	.431	-1.749	.249
	9	-.650	.293	1.000	-1.773	.473
	10	-.250	.239	1.000	-1.168	.668
4	1	.550	.246	1.000	-.393	1.493
	2	-.200	.287	1.000	-1.300	.900
	3	.250	.260	1.000	-.749	1.249
	5	-.200	.225	1.000	-1.063	.663
	6	-.400	.234	1.000	-1.298	.498
	7	.000	.363	1.000	-1.392	1.392
	8	-.500	.199	.945	-1.262	.262
	9	-.400	.184	1.000	-1.104	.304
	10	.000	.271	1.000	-1.042	1.042
5	1	.750	.280	.666	-.324	1.824
	2	.000	.340	1.000	-1.306	1.306
	3	.450	.344	1.000	-.870	1.770
	4	.200	.225	1.000	-.663	1.063
	6	-.200	.200	1.000	-.967	.567
	7	.200	.329	1.000	-1.064	1.464
	8	-.300	.272	1.000	-1.345	.745
	9	-.200	.172	1.000	-.859	.459
	10	.200	.321	1.000	-1.032	1.432

Pairwise Comparisons

Measure: MEASURE_1

(I) Seat	(J) Seat	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
6	1	.950*	.235	.031	.049	1.851
	2	.200	.268	1.000	-.827	1.227
	3	.650	.350	1.000	-.693	1.993
	4	.400	.234	1.000	-.498	1.298
	5	.200	.200	1.000	-.567	.967
	7	.400	.255	1.000	-.580	1.380
	8	-.100	.204	1.000	-.882	.682
	9	.000	.192	1.000	-.737	.737
	10	.400	.294	1.000	-.727	1.527
7	1	.550	.266	1.000	-.472	1.572
	2	-.200	.213	1.000	-1.016	.616
	3	.250	.347	1.000	-1.081	1.581
	4	.000	.363	1.000	-1.392	1.392
	5	-.200	.329	1.000	-1.464	1.064
	6	-.400	.255	1.000	-1.380	.580
	8	-.500	.276	1.000	-1.560	.560
	9	-.400	.275	1.000	-1.456	.656
	10	.000	.229	1.000	-.880	.880
8	1	1.050*	.223	.007	.193	1.907
	2	.300	.252	1.000	-.668	1.268
	3	.750	.260	.431	-.249	1.749
	4	.500	.199	.945	-.262	1.262
	5	.300	.272	1.000	-.745	1.345
	6	.100	.204	1.000	-.682	.882
	7	.500	.276	1.000	-.560	1.560
	9	.100	.216	1.000	-.731	.931
	10	.500	.224	1.000	-.358	1.358
9	1	.950	.256	.067	-.033	1.933
	2	.200	.277	1.000	-.864	1.264
	3	.650	.293	1.000	-.473	1.773
	4	.400	.184	1.000	-.304	1.104
	5	.200	.172	1.000	-.459	.859
	6	.000	.192	1.000	-.737	.737
	7	.400	.275	1.000	-.656	1.456
	8	-.100	.216	1.000	-.931	.731
	10	.400	.234	1.000	-.498	1.298
10	1	.550	.276	1.000	-.509	1.609
	2	-.200	.186	1.000	-.915	.515
	3	.250	.239	1.000	-.668	1.168
	4	.000	.271	1.000	-1.042	1.042
	5	-.200	.321	1.000	-1.432	1.032
	6	-.400	.294	1.000	-1.527	.727
	7	.000	.229	1.000	-.880	.880
	8	-.500	.224	1.000	-1.358	.358
	9	-.400	.234	1.000	-1.298	.498

Based on estimated marginal means
*. The mean difference is significant at the
b. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	.721	3.152[a]	9.000	11.000	.038	.721
Wilks' lambda	.279	3.152[a]	9.000	11.000	.038	.721
Hotelling's trace	2.579	3.152[a]	9.000	11.000	.038	.721
Roy's largest root	2.579	3.152[a]	9.000	11.000	.038	.721

Each F tests the multivariate effect of Seat. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.
a. Exact statistic

```
GLM A4 B4 C4 D4 E4 F4 G4 H4 I4 J4
 /WSFACTOR=Seat 10 Polynomial
 /METHOD=SSTYPE(3)
 /EMMEANS=TABLES(Seat) COMPARE ADJ(BONFERRONI)
 /PRINT=DESCRIPTIVE ETASQ
 /CRITERIA=ALPHA(.05)
 /WSDESIGN=Seat.
```

General Linear Model

Notes

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Within-Subjects Factors

Measure: MEASURE_1

Seat	Dependent Variable
1	A4
2	B4
3	C4
4	D4
5	E4
6	F4
7	G4
8	H4
9	I4
10	J4

Descriptive Statistics

	Mean	Std. Deviation	N
A4	2.3889	.69780	18
B4	2.7778	.42779	18
C4	2.5000	.61835	18
D4	2.6667	.59409	18
E4	2.8333	.38348	18
F4	2.5556	.70479	18
G4	2.7778	.54832	18
H4	2.8333	.38348	18
I4	2.7778	.54832	18
J4	2.8333	.38348	18

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Seat	Pillai's Trace	.653	1.879[b]	9.000	9.000	.181	.653
	Wilks' Lambda	.347	1.879[b]	9.000	9.000	.181	.653
	Hotelling's Trace	1.879	1.879[b]	9.000	9.000	.181	.653
	Roy's Largest Root	1.879	1.879[b]	9.000	9.000	.181	.653

a. Design: Intercept
Within Subjects Design: Seat

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Epsilon[b] Huynh-Feldt	Epsilon[b] Lower-bound
Seat	.003	81.291	44	.001	.500	.702	.111

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Seat

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Seat	Sphericity Assumed	4.139	9	.460	1.873	.060	.099
	Greenhouse-Geisser	4.139	4.499	.920	1.873	.116	.099
	Huynh-Feldt	4.139	6.318	.655	1.873	.088	.099
	Lower-bound	4.139	1.000	4.139	1.873	.189	.099
Error(Seat)	Sphericity Assumed	37.561	153	.245			
	Greenhouse-Geisser	37.561	76.482	.491			
	Huynh-Feldt	37.561	107.405	.350			
	Lower-bound	37.561	17.000	2.209			

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Seat	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Seat	Linear	1.786	1	1.786	6.576	.020	.279
	Quadratic	.082	1	.082	.530	.476	.030
	Cubic	.100	1	.100	.223	.643	.013
	Order 4	.194	1	.194	1.158	.297	.064
	Order 5	.151	1	.151	.430	.521	.025
	Order 6	.178	1	.178	.628	.439	.036
	Order 7	1.171	1	1.171	9.252	.007	.352
	Order 8	.101	1	.101	.515	.483	.029
	Order 9	.376	1	.376	1.773	.201	.094
Error(Seat)	Linear	4.617	17	.272			
	Quadratic	2.645	17	.156			
	Cubic	7.578	17	.446			
	Order 4	2.852	17	.168			
	Order 5	5.962	17	.351			
	Order 6	4.822	17	.284			
	Order 7	2.151	17	.127			
	Order 8	3.326	17	.196			
	Order 9	3.609	17	.212			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1306.806	1	1306.806	1778.046	.000	.991
Error	12.494	17	.735			

Estimated Marginal Means

Seat

Estimates

Measure: MEASURE_1

Seat	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	2.389	.164	2.042	2.736
2	2.778	.101	2.565	2.991
3	2.500	.146	2.193	2.807
4	2.667	.140	2.371	2.962
5	2.833	.090	2.643	3.024
6	2.556	.166	2.205	2.906
7	2.778	.129	2.505	3.050
8	2.833	.090	2.643	3.024
9	2.778	.129	2.505	3.050
10	2.833	.090	2.643	3.024

Pairwise Comparisons

Measure: MEASURE_1

(I) Seat	(J) Seat	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.389	.183	1.000	-1.107	.329
	3	-.111	.212	1.000	-.942	.720
	4	-.278	.240	1.000	-1.217	.662
	5	-.444	.185	1.000	-1.168	.279
	6	-.167	.218	1.000	-1.019	.686
	7	-.389	.183	1.000	-1.107	.329
	8	-.444	.185	1.000	-1.168	.279
	9	-.389	.216	1.000	-1.235	.457
	10	-.444	.202	1.000	-1.234	.345
2	1	.389	.183	1.000	-.329	1.107
	3	.278	.158	1.000	-.340	.895
	4	.111	.159	1.000	-.513	.736
	5	-.056	.127	1.000	-.553	.442
	6	.222	.101	1.000	-.173	.617
	7	.000	.114	1.000	-.448	.448
	8	-.056	.098	1.000	-.440	.329
	9	.000	.114	1.000	-.448	.448
	10	-.056	.098	1.000	-.440	.329
3	1	.111	.212	1.000	-.720	.942
	2	-.278	.158	1.000	-.895	.340
	4	-.167	.167	1.000	-.819	.486
	5	-.333	.140	1.000	-.882	.215
	6	-.056	.235	1.000	-.977	.866
	7	-.278	.226	1.000	-1.162	.607
	8	-.333	.162	1.000	-.967	.300
	9	-.278	.195	1.000	-1.041	.485
	10	-.333	.162	1.000	-.967	.300
4	1	.278	.240	1.000	-.662	1.217
	2	-.111	.159	1.000	-.736	.513
	3	.167	.167	1.000	-.486	.819
	5	-.167	.167	1.000	-.819	.486
	6	.111	.212	1.000	-.720	.942
	7	-.111	.196	1.000	-.879	.657
	8	-.167	.146	1.000	-.737	.404
	9	-.111	.137	1.000	-.649	.427
	10	-.167	.121	1.000	-.642	.308
5	1	.444	.185	1.000	-.279	1.168
	2	.056	.127	1.000	-.442	.553
	3	.333	.140	1.000	-.215	.882
	4	.167	.167	1.000	-.486	.819
	6	.278	.195	1.000	-.485	1.041
	7	.056	.171	1.000	-.614	.725
	8	.000	.140	1.000	-.548	.548
	9	.056	.151	1.000	-.534	.646
	10	.000	.140	1.000	-.548	.548

Pairwise Comparisons

Measure: MEASURE_1

(I) Seat	(J) Seat	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
6	1	.167	.218	1.000	-.686	1.019
	2	-.222	.101	1.000	-.617	.173
	3	.056	.235	1.000	-.866	.977
	4	-.111	.212	1.000	-.942	.720
	5	-.278	.195	1.000	-1.041	.485
	7	-.222	.101	1.000	-.617	.173
	8	-.278	.158	1.000	-.895	.340
	9	-.222	.152	1.000	-.819	.375
	10	-.278	.158	1.000	-.895	.340
7	1	.389	.183	1.000	-.329	1.107
	2	.000	.114	1.000	-.448	.448
	3	.278	.226	1.000	-.607	1.162
	4	.111	.196	1.000	-.657	.879
	5	-.056	.171	1.000	-.725	.614
	6	.222	.101	1.000	-.173	.617
	8	-.056	.127	1.000	-.553	.442
	9	.000	.162	1.000	-.633	.633
	10	-.056	.127	1.000	-.553	.442
8	1	.444	.185	1.000	-.279	1.168
	2	.056	.098	1.000	-.329	.440
	3	.333	.162	1.000	-.300	.967
	4	.167	.146	1.000	-.404	.737
	5	.000	.140	1.000	-.548	.548
	6	.278	.158	1.000	-.340	.895
	7	.056	.127	1.000	-.442	.553
	9	.056	.151	1.000	-.534	.646
	10	.000	.081	1.000	-.317	.317
9	1	.389	.216	1.000	-.457	1.235
	2	.000	.114	1.000	-.448	.448
	3	.278	.195	1.000	-.485	1.041
	4	.111	.137	1.000	-.427	.649
	5	-.056	.151	1.000	-.646	.534
	6	.222	.152	1.000	-.375	.819
	7	.000	.162	1.000	-.633	.633
	8	-.056	.151	1.000	-.646	.534
	10	-.056	.151	1.000	-.646	.534
10	1	.444	.202	1.000	-.345	1.234
	2	.056	.098	1.000	-.329	.440
	3	.333	.162	1.000	-.300	.967
	4	.167	.121	1.000	-.308	.642
	5	.000	.140	1.000	-.548	.548
	6	.278	.158	1.000	-.340	.895
	7	.056	.127	1.000	-.442	.553
	8	.000	.081	1.000	-.317	.317
	9	.056	.151	1.000	-.534	.646

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	.653	1.879[a]	9.000	9.000	.181	.653
Wilks' lambda	.347	1.879[a]	9.000	9.000	.181	.653
Hotelling's trace	1.879	1.879[a]	9.000	9.000	.181	.653
Roy's largest root	1.879	1.879[a]	9.000	9.000	.181	.653

Each F tests the multivariate effect of Seat. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

```
GLM A5 B5 C5 D5 E5 F5 G5 H5 I5 J5
  /WSFACTOR=Seat 10 Polynomial
  /METHOD=SSTYPE(3)
  /EMMEANS=TABLES(Seat) COMPARE ADJ(BONFERRONI)
  /PRINT=DESCRIPTIVE ETASQ
  /CRITERIA=ALPHA(.05)
  /WSDESIGN=Seat.
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General Linear Model

Notes

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Within-Subjects Factors

Measure: MEASURE_1

Seat	Dependent Variable
1	A5
2	B5
3	C5
4	D5
5	E5
6	F5
7	G5
8	H5
9	I5
10	J5

Descriptive Statistics

	Mean	Std. Deviation	N
A5	3.8421	1.16729	19
B5	3.9474	.91127	19
C5	2.4737	1.07333	19
D5	3.8421	1.16729	19
E5	4.0000	1.15470	19
F5	3.6842	1.24956	19
G5	3.7895	1.39758	19
H5	4.1579	.89834	19
I5	4.2105	.97633	19
J5	4.3158	1.10818	19

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Seat	Pillai's Trace	.837	5.688[b]	9.000	10.000	.006	.837
	Wilks' Lambda	.163	5.688[b]	9.000	10.000	.006	.837
	Hotelling's Trace	5.120	5.688[b]	9.000	10.000	.006	.837
	Roy's Largest Root	5.120	5.688[b]	9.000	10.000	.006	.837

a. Design: Intercept
Within Subjects Design: Seat

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Seat	.008	70.900	44	.009	.540	.764	.111

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Seat

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Seat	Sphericity Assumed	45.479	9	5.053	7.635	.000	.298
	Greenhouse-Geisser	45.479	4.862	9.354	7.635	.000	.298
	Huynh-Feldt	45.479	6.879	6.611	7.635	.000	.298
	Lower-bound	45.479	1.000	45.479	7.635	.013	.298
Error(Seat)	Sphericity Assumed	107.221	162	.662			
	Greenhouse-Geisser	107.221	87.516	1.225			
	Huynh-Feldt	107.221	123.825	.866			
	Lower-bound	107.221	18.000	5.957			

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Seat	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Seat	Linear	11.370	1	11.370	13.730	.002	.433
	Quadratic	3.598	1	3.598	4.682	.044	.206
	Cubic	3.084	1	3.084	5.148	.036	.222
	Order 4	1.667	1	1.667	2.878	.107	.138
	Order 5	.065	1	.065	.133	.719	.007
	Order 6	6.163	1	6.163	8.049	.011	.309
	Order 7	15.979	1	15.979	32.872	.000	.646
	Order 8	3.340	1	3.340	5.788	.027	.243
	Order 9	.213	1	.213	.246	.626	.014
Error(Seat)	Linear	14.906	18	.828			
	Quadratic	13.833	18	.769			
	Cubic	10.782	18	.599			
	Order 4	10.430	18	.579			
	Order 5	8.767	18	.487			
	Order 6	13.782	18	.766			
	Order 7	8.750	18	.486			
	Order 8	10.386	18	.577			
	Order 9	15.584	18	.866			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	2781.732	1	2781.732	422.298	.000	.959
Error	118.568	18	6.587			

Estimated Marginal Means

Seat

Estimates

Measure: MEASURE_1

Seat	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	3.842	.268	3.279	4.405
2	3.947	.209	3.508	4.387
3	2.474	.246	1.956	2.991
4	3.842	.268	3.279	4.405
5	4.000	.265	3.443	4.557
6	3.684	.287	3.082	4.286
7	3.789	.321	3.116	4.463
8	4.158	.206	3.725	4.591
9	4.211	.224	3.740	4.681
10	4.316	.254	3.782	4.850

Pairwise Comparisons

Measure: MEASURE_1

(I) Seat	(J) Seat	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-.105	.130	1.000	-.609	.399
	3	1.368*	.267	.003	.333	2.404
	4	.000	.202	1.000	-.784	.784
	5	-.158	.299	1.000	-1.315	1.000
	6	.158	.308	1.000	-1.037	1.353
	7	.053	.223	1.000	-.810	.915
	8	-.316	.265	1.000	-1.344	.713
	9	-.368	.191	1.000	-1.107	.370
	10	-.474	.319	1.000	-1.708	.761
2	1	.105	.130	1.000	-.399	.609
	3	1.474*	.234	.000	.567	2.381
	4	.105	.169	1.000	-.550	.761
	5	-.053	.235	1.000	-.965	.859
	6	.263	.252	1.000	-.712	1.239
	7	.158	.206	1.000	-.641	.956
	8	-.211	.196	1.000	-.970	.549
	9	-.263	.150	1.000	-.844	.318
	10	-.368	.267	1.000	-1.404	.667
3	1	-1.368*	.267	.003	-2.404	-.333
	2	-1.474*	.234	.000	-2.381	-.567
	4	-1.368*	.317	.019	-2.598	-.139
	5	-1.526*	.353	.019	-2.896	-.157
	6	-1.211	.363	.167	-2.618	.197
	7	-1.316*	.242	.002	-2.255	-.376
	8	-1.684*	.242	.000	-2.624	-.745
	9	-1.737*	.274	.000	-2.799	-.675
	10	-1.842*	.289	.000	-2.961	-.723
4	1	.000	.202	1.000	-.784	.784
	2	-.105	.169	1.000	-.761	.550
	3	1.368*	.317	.019	.139	2.598
	5	-.158	.206	1.000	-.956	.641
	6	.158	.191	1.000	-.584	.899
	7	.053	.291	1.000	-1.075	1.180
	8	-.316	.242	1.000	-1.255	.624
	9	-.368	.191	1.000	-1.107	.370
	10	-.474	.319	1.000	-1.708	.761
5	1	.158	.299	1.000	-1.000	1.315
	2	.053	.235	1.000	-.859	.965
	3	1.526*	.353	.019	.157	2.896
	4	.158	.206	1.000	-.641	.956
	6	.316	.276	1.000	-.755	1.386
	7	.211	.355	1.000	-1.166	1.587
	8	-.158	.308	1.000	-1.353	1.037
	9	-.211	.237	1.000	-1.128	.706
	10	-.316	.316	1.000	-1.539	.908

Pairwise Comparisons

Measure: MEASURE_1

(I) Seat	(J) Seat	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
6	1	-.158	.308	1.000	-1.353	1.037
	2	-.263	.252	1.000	-1.239	.712
	3	1.211	.363	.167	-.197	2.618
	4	-.158	.191	1.000	-.899	.584
	5	-.316	.276	1.000	-1.386	.755
	7	-.105	.341	1.000	-1.427	1.216
	8	-.474	.234	1.000	-1.381	.433
	9	-.526	.258	1.000	-1.525	.473
	10	-.632	.352	1.000	-1.996	.733
7	1	-.053	.223	1.000	-.915	.810
	2	-.158	.206	1.000	-.956	.641
	3	1.316*	.242	.002	.376	2.255
	4	-.053	.291	1.000	-1.180	1.075
	5	-.211	.355	1.000	-1.587	1.166
	6	.105	.341	1.000	-1.216	1.427
	8	-.368	.267	1.000	-1.404	.667
	9	-.421	.221	1.000	-1.275	.433
	10	-.526	.290	1.000	-1.649	.597
8	1	.316	.265	1.000	-.713	1.344
	2	.211	.196	1.000	-.549	.970
	3	1.684*	.242	.000	.745	2.624
	4	.316	.242	1.000	-.624	1.255
	5	.158	.308	1.000	-1.037	1.353
	6	.474	.234	1.000	-.433	1.381
	7	.368	.267	1.000	-.667	1.404
	9	-.053	.179	1.000	-.746	.641
	10	-.158	.268	1.000	-1.195	.880
9	1	.368	.191	1.000	-.370	1.107
	2	.263	.150	1.000	-.318	.844
	3	1.737*	.274	.000	.675	2.799
	4	.368	.191	1.000	-.370	1.107
	5	.211	.237	1.000	-.706	1.128
	6	.526	.258	1.000	-.473	1.525
	7	.421	.221	1.000	-.433	1.275
	8	.053	.179	1.000	-.641	.746
	10	-.105	.264	1.000	-1.127	.917
10	1	.474	.319	1.000	-.761	1.708
	2	.368	.267	1.000	-.667	1.404
	3	1.842*	.289	.000	.723	2.961
	4	.474	.319	1.000	-.761	1.708
	5	.316	.316	1.000	-.908	1.539
	6	.632	.352	1.000	-.733	1.996
	7	.526	.290	1.000	-.597	1.649
	8	.158	.268	1.000	-.880	1.195
	9	.105	.264	1.000	-.917	1.127

Based on estimated marginal means

*. The mean difference is significant at the

b. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	.837	5.688[a]	9.000	10.000	.006	.837
Wilks' lambda	.163	5.688[a]	9.000	10.000	.006	.837
Hotelling's trace	5.120	5.688[a]	9.000	10.000	.006	.837
Roy's largest root	5.120	5.688[a]	9.000	10.000	.006	.837

Each F tests the multivariate effect of Seat. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

```
GLM A6 B6 C6 D6 E6 F6 G6 H6 I6 J6
 /WSFACTOR=Seat 10 Polynomial
 /METHOD=SSTYPE(3)
 /EMMEANS=TABLES(Seat) COMPARE ADJ(BONFERRONI)
 /PRINT=DESCRIPTIVE ETASQ
 /CRITERIA=ALPHA(.05)
 /WSDESIGN=Seat.
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General Linear Model

Notes

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Within-Subjects Factors

Measure: MEASURE_1

Seat	Dependent Variable
1	A6
2	B6
3	C6
4	D6
5	E6
6	F6
7	G6
8	H6
9	I6
10	J6

Descriptive Statistics

	Mean	Std. Deviation	N
A6	3.9000	1.02084	20
B6	4.1500	.81273	20
C6	3.6500	1.03999	20
D6	4.2000	.95145	20
E6	4.0000	.85840	20
F6	4.1500	.98809	20
G6	3.7500	1.11803	20
H6	4.0500	.88704	20
I6	4.3000	.86450	20
J6	4.1500	.87509	20

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Seat	Pillai's Trace	.620	1.998[b]	9.000	11.000	.139	.620
	Wilks' Lambda	.380	1.998[b]	9.000	11.000	.139	.620
	Hotelling's Trace	1.635	1.998[b]	9.000	11.000	.139	.620
	Roy's Largest Root	1.635	1.998[b]	9.000	11.000	.139	.620

a. Design: Intercept
Within Subjects Design: Seat

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Seat	.003	90.635	44	.000	.513	.698	.111

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Seat

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Seat	Sphericity Assumed	7.720	9	.858	1.975	.045	.094
	Greenhouse-Geisser	7.720	4.618	1.672	1.975	.096	.094
	Huynh-Feldt	7.720	6.284	1.229	1.975	.071	.094
	Lower-bound	7.720	1.000	7.720	1.975	.176	.094
Error(Seat)	Sphericity Assumed	74.280	171	.434			
	Greenhouse-Geisser	74.280	87.750	.846			
	Huynh-Feldt	74.280	119.389	.622			
	Lower-bound	74.280	19.000	3.909			

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Seat	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Seat	Linear	1.019	1	1.019	2.224	.152	.105
	Quadratic	.167	1	.167	.328	.574	.017
	Cubic	.100	1	.100	.235	.633	.012
	Order 4	.013	1	.013	.024	.877	.001
	Order 5	.463	1	.463	1.100	.307	.055
	Order 6	2.621	1	2.621	6.391	.020	.252
	Order 7	1.102	1	1.102	2.569	.126	.119
	Order 8	.219	1	.219	.903	.354	.045
	Order 9	2.016	1	2.016	4.093	.057	.177
Error(Seat)	Linear	8.702	19	.458			
	Quadratic	9.689	19	.510			
	Cubic	8.086	19	.426			
	Order 4	9.884	19	.520			
	Order 5	8.000	19	.421			
	Order 6	7.791	19	.410			
	Order 7	8.155	19	.429			
	Order 8	4.616	19	.243			
	Order 9	9.357	19	.492			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	3248.180	1	3248.180	644.077	.000	.971
Error	95.820	19	5.043			

Estimated Marginal Means

Seat

Estimates

Measure: MEASURE_1

Seat	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	3.900	.228	3.422	4.378
2	4.150	.182	3.770	4.530
3	3.650	.233	3.163	4.137
4	4.200	.213	3.755	4.645
5	4.000	.192	3.598	4.402
6	4.150	.221	3.688	4.612
7	3.750	.250	3.227	4.273
8	4.050	.198	3.635	4.465
9	4.300	.193	3.895	4.705
10	4.150	.196	3.740	4.560

Pairwise Comparisons

Measure: MEASURE_1

(I) Seat	(J) Seat	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.250	.143	1.000	-.798	.298
	3	.250	.176	1.000	-.425	.925
	4	-.300	.179	1.000	-.988	.388
	5	-.100	.216	1.000	-.931	.731
	6	-.250	.204	1.000	-1.031	.531
	7	.150	.244	1.000	-.785	1.085
	8	-.150	.182	1.000	-.847	.547
	9	-.400	.152	.745	-.984	.184
	10	-.250	.228	1.000	-1.125	.625
2	1	.250	.143	1.000	-.298	.798
	3	.500	.170	.379	-.153	1.153
	4	-.050	.170	1.000	-.701	.601
	5	.150	.221	1.000	-.698	.998
	6	.000	.178	1.000	-.682	.682
	7	.400	.210	1.000	-.407	1.207
	8	.100	.161	1.000	-.516	.716
	9	-.150	.150	1.000	-.726	.426
	10	.000	.192	1.000	-.737	.737
3	1	-.250	.176	1.000	-.925	.425
	2	-.500	.170	.379	-1.153	.153
	4	-.550	.266	1.000	-1.572	.472
	5	-.350	.274	1.000	-1.402	.702
	6	-.500	.276	1.000	-1.560	.560
	7	-.100	.176	1.000	-.776	.576
	8	-.400	.222	1.000	-1.254	.454
	9	-.650	.221	.377	-1.498	.198
	10	-.500	.256	1.000	-1.484	.484
4	1	.300	.179	1.000	-.388	.988
	2	.050	.170	1.000	-.601	.701
	3	.550	.266	1.000	-.472	1.572
	5	.200	.156	1.000	-.397	.797
	6	.050	.135	1.000	-.469	.569
	7	.450	.256	1.000	-.533	1.433
	8	.150	.209	1.000	-.651	.951
	9	-.100	.143	1.000	-.650	.450
	10	.050	.198	1.000	-.711	.811
5	1	.100	.216	1.000	-.731	.931
	2	-.150	.221	1.000	-.998	.698
	3	.350	.274	1.000	-.702	1.402
	4	-.200	.156	1.000	-.797	.397
	6	-.150	.182	1.000	-.847	.547
	7	.250	.270	1.000	-.787	1.287
	8	-.050	.198	1.000	-.811	.711
	9	-.300	.164	1.000	-.929	.329
	10	-.150	.209	1.000	-.951	.651

Pairwise Comparisons

Measure: MEASURE_1

(I) Seat	(J) Seat	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
6	1	.250	.204	1.000	-.531	1.031
	2	.000	.178	1.000	-.682	.682
	3	.500	.276	1.000	-.560	1.560
	4	-.050	.135	1.000	-.569	.469
	5	.150	.182	1.000	-.547	.847
	7	.400	.275	1.000	-.656	1.456
	8	.100	.240	1.000	-.819	1.019
	9	-.150	.196	1.000	-.901	.601
	10	.000	.241	1.000	-.923	.923
7	1	-.150	.244	1.000	-1.085	.785
	2	-.400	.210	1.000	-1.207	.407
	3	.100	.176	1.000	-.576	.776
	4	-.450	.256	1.000	-1.433	.533
	5	-.250	.270	1.000	-1.287	.787
	6	-.400	.275	1.000	-1.456	.656
	8	-.300	.206	1.000	-1.092	.492
	9	-.550	.223	1.000	-1.407	.307
	10	-.400	.294	1.000	-1.527	.727
8	1	.150	.182	1.000	-.547	.847
	2	-.100	.161	1.000	-.716	.516
	3	.400	.222	1.000	-.454	1.254
	4	-.150	.209	1.000	-.951	.651
	5	.050	.198	1.000	-.711	.811
	6	-.100	.240	1.000	-1.019	.819
	7	.300	.206	1.000	-.492	1.092
	9	-.250	.099	.945	-.631	.131
	10	-.100	.216	1.000	-.931	.731
9	1	.400	.152	.745	-.184	.984
	2	.150	.150	1.000	-.426	.726
	3	.650	.221	.377	-.198	1.498
	4	.100	.143	1.000	-.450	.650
	5	.300	.164	1.000	-.329	.929
	6	.150	.196	1.000	-.601	.901
	7	.550	.223	1.000	-.307	1.407
	8	.250	.099	.945	-.131	.631
	10	.150	.196	1.000	-.601	.901
10	1	.250	.228	1.000	-.625	1.125
	2	.000	.192	1.000	-.737	.737
	3	.500	.256	1.000	-.484	1.484
	4	-.050	.198	1.000	-.811	.711
	5	.150	.209	1.000	-.651	.951
	6	.000	.241	1.000	-.923	.923
	7	.400	.294	1.000	-.727	1.527
	8	.100	.216	1.000	-.731	.931
	9	-.150	.196	1.000	-.901	.601

Based on estimated marginal means
a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	.620	1.998[a]	9.000	11.000	.139	.620
Wilks' lambda	.380	1.998[a]	9.000	11.000	.139	.620
Hotelling's trace	1.635	1.998[a]	9.000	11.000	.139	.620
Roy's largest root	1.635	1.998[a]	9.000	11.000	.139	.620

Each F tests the multivariate effect of Seat. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.
a. Exact statistic

```
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 /METHOD=SSTYPE(3)
 /EMMEANS=TABLES(Seat) COMPARE ADJ(BONFERRONI)
 /PRINT=DESCRIPTIVE ETASQ
 /CRITERIA=ALPHA(.05)
 /WSDESIGN=Seat.
```

General Linear Model

Notes

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Within-Subjects Factors

Measure: MEASURE_1

Seat	Dependent Variable
1	A7
2	B7
3	C7
4	D7
5	E7
6	F7
7	G7
8	H7
9	I7
10	J7

Descriptive Statistics

	Mean	Std. Deviation	N
A7	3.0526	1.39338	19
B7	3.4211	1.38707	19
C7	2.5789	1.26121	19
D7	3.5263	1.26352	19
E7	3.5263	1.07333	19
F7	3.4737	1.30675	19
G7	3.0000	1.37437	19
H7	3.8421	1.11869	19
I7	3.8421	1.11869	19
J7	3.4211	1.50243	19

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Seat	Pillai's Trace	.789	4.149[b]	9.000	10.000	.018	.789
	Wilks' Lambda	.211	4.149[b]	9.000	10.000	.018	.789
	Hotelling's Trace	3.734	4.149[b]	9.000	10.000	.018	.789
	Roy's Largest Root	3.734	4.149[b]	9.000	10.000	.018	.789

a. Design: Intercept
Within Subjects Design: Seat

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Seat	.005	78.782	44	.002	.550	.784	.111

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Seat

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Seat	Sphericity Assumed	26.105	9	2.901	3.686	.000	.170
	Greenhouse-Geisser	26.105	4.953	5.271	3.686	.005	.170
	Huynh-Feldt	26.105	7.059	3.698	3.686	.001	.170
	Lower-bound	26.105	1.000	26.105	3.686	.071	.170
Error(Seat)	Sphericity Assumed	127.495	162	.787			
	Greenhouse-Geisser	127.495	89.149	1.430			
	Huynh-Feldt	127.495	127.064	1.003			
	Lower-bound	127.495	18.000	7.083			

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Seat	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Seat	Linear	6.900	1	6.900	4.501	.048	.200
	Quadratic	.057	1	.057	.062	.806	.003
	Cubic	.693	1	.693	.855	.368	.045
	Order 4	.311	1	.311	.611	.445	.033
	Order 5	1.771	1	1.771	1.738	.204	.088
	Order 6	4.944	1	4.944	7.795	.012	.302
	Order 7	8.948	1	8.948	14.196	.001	.441
	Order 8	.003	1	.003	.006	.938	.000
	Order 9	2.478	1	2.478	4.778	.042	.210
Error(Seat)	Linear	27.597	18	1.533			
	Quadratic	16.685	18	.927			
	Cubic	14.588	18	.810			
	Order 4	9.167	18	.509			
	Order 5	18.345	18	1.019			
	Order 6	11.418	18	.634			
	Order 7	11.345	18	.630			
	Order 8	9.015	18	.501			
	Order 9	9.336	18	.519			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	2155.789	1	2155.789	227.443	.000	.927
Error	170.611	18	9.478			

Estimated Marginal Means

Seat

Estimates

Measure: MEASURE_1

Seat	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	3.053	.320	2.381	3.724
2	3.421	.318	2.753	4.090
3	2.579	.289	1.971	3.187
4	3.526	.290	2.917	4.135
5	3.526	.246	3.009	4.044
6	3.474	.300	2.844	4.104
7	3.000	.315	2.338	3.662
8	3.842	.257	3.303	4.381
9	3.842	.257	3.303	4.381
10	3.421	.345	2.697	4.145

Pairwise Comparisons

Measure: MEASURE_1

(I) Seat	(J) Seat	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	-.368	.137	.675	-.899	.162
	3	.474	.280	1.000	-.610	1.557
	4	-.474	.258	1.000	-1.473	.525
	5	-.474	.328	1.000	-1.743	.796
	6	-.421	.327	1.000	-1.689	.847
	7	.053	.310	1.000	-1.150	1.255
	8	-.789	.282	.531	-1.881	.302
	9	-.789	.237	.166	-1.706	.128
	10	-.368	.352	1.000	-1.733	.996
2	1	.368	.137	.675	-.162	.899
	3	.842	.299	.512	-.315	2.000
	4	-.105	.275	1.000	-1.169	.959
	5	-.105	.323	1.000	-1.359	1.148
	6	-.053	.310	1.000	-1.255	1.150
	7	.421	.336	1.000	-.881	1.723
	8	-.421	.309	1.000	-1.618	.776
	9	-.421	.279	1.000	-1.502	.660
	10	.000	.315	1.000	-1.222	1.222
3	1	-.474	.280	1.000	-1.557	.610
	2	-.842	.299	.512	-2.000	.315
	4	-.947	.270	.113	-1.994	.099
	5	-.947	.310	.309	-2.150	.255
	6	-.895	.374	1.000	-2.343	.554
	7	-.421	.361	1.000	-1.821	.979
	8	-1.263*	.304	.027	-2.442	-.084
	9	-1.263	.332	.058	-2.549	.023
	10	-.842	.369	1.000	-2.271	.587
4	1	.474	.258	1.000	-.525	1.473
	2	.105	.275	1.000	-.959	1.169
	3	.947	.270	.113	-.099	1.994
	5	.000	.187	1.000	-.726	.726
	6	.053	.247	1.000	-.906	1.011
	7	.526	.353	1.000	-.843	1.896
	8	-.316	.188	1.000	-1.045	.413
	9	-.316	.203	1.000	-1.103	.471
	10	.105	.323	1.000	-1.148	1.359
5	1	.474	.328	1.000	-.796	1.743
	2	.105	.323	1.000	-1.148	1.359
	3	.947	.310	.309	-.255	2.150
	4	.000	.187	1.000	-.726	.726
	6	.053	.235	1.000	-.859	.965
	7	.526	.337	1.000	-.778	1.830
	8	-.316	.154	1.000	-.912	.281
	9	-.316	.188	1.000	-1.045	.413
	10	.105	.305	1.000	-1.076	1.286

Pairwise Comparisons

Measure: MEASURE_1

(I) Seat	(J) Seat	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
6	1	.421	.327	1.000	-.847	1.689
	2	.053	.310	1.000	-1.150	1.255
	3	.895	.374	1.000	-.554	2.343
	4	-.053	.247	1.000	-1.011	.906
	5	-.053	.235	1.000	-.965	.859
	7	.474	.290	1.000	-.649	1.597
	8	-.368	.256	1.000	-1.360	.624
	9	-.368	.219	1.000	-1.217	.481
	10	.053	.259	1.000	-.951	1.056
7	1	-.053	.310	1.000	-1.255	1.150
	2	-.421	.336	1.000	-1.723	.881
	3	.421	.361	1.000	-.979	1.821
	4	-.526	.353	1.000	-1.896	.843
	5	-.526	.337	1.000	-1.830	.778
	6	-.474	.290	1.000	-1.597	.649
	8	-.842	.318	.732	-2.073	.389
	9	-.842	.279	.328	-1.921	.237
	10	-.421	.289	1.000	-1.542	.700
8	1	.789	.282	.531	-.302	1.881
	2	.421	.309	1.000	-.776	1.618
	3	1.263*	.304	.027	.084	2.442
	4	.316	.188	1.000	-.413	1.045
	5	.316	.154	1.000	-.281	.912
	6	.368	.256	1.000	-.624	1.360
	7	.842	.318	.732	-.389	2.073
	9	.000	.153	1.000	-.593	.593
	10	.421	.309	1.000	-.776	1.618
9	1	.789	.237	.166	-.128	1.706
	2	.421	.279	1.000	-.660	1.502
	3	1.263	.332	.058	-.023	2.549
	4	.316	.203	1.000	-.471	1.103
	5	.316	.188	1.000	-.413	1.045
	6	.368	.219	1.000	-.481	1.217
	7	.842	.279	.328	-.237	1.921
	8	.000	.153	1.000	-.593	.593
	10	.421	.309	1.000	-.776	1.618
10	1	.368	.352	1.000	-.996	1.733
	2	.000	.315	1.000	-1.222	1.222
	3	.842	.369	1.000	-.587	2.271
	4	-.105	.323	1.000	-1.359	1.148
	5	-.105	.305	1.000	-1.286	1.076
	6	-.053	.259	1.000	-1.056	.951
	7	.421	.289	1.000	-.700	1.542
	8	-.421	.309	1.000	-1.618	.776
	9	-.421	.309	1.000	-1.618	.776

Based on estimated marginal means

*. The mean difference is significant at the

b. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	.789	4.149[a]	9.000	10.000	.018	.789
Wilks' lambda	.211	4.149[a]	9.000	10.000	.018	.789
Hotelling's trace	3.734	4.149[a]	9.000	10.000	.018	.789
Roy's largest root	3.734	4.149[a]	9.000	10.000	.018	.789

Each F tests the multivariate effect of Seat. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

```
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  /METHOD=SSTYPE(3)
  /EMMEANS=TABLES(Seat) COMPARE ADJ(BONFERRONI)
  /PRINT=DESCRIPTIVE ETASQ
  /CRITERIA=ALPHA(.05)
  /WSDESIGN=Seat.
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General Linear Model

Notes

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Within-Subjects Factors

Measure: MEASURE_1

Seat	Dependent Variable
1	A8
2	B8
3	C8
4	D8
5	E8
6	F8
7	G8
8	H8
9	I8
10	J8

Descriptive Statistics

	Mean	Std. Deviation	N
A8	2.1053	.45883	19
B8	2.1053	.45883	19
C8	2.0526	.40465	19
D8	2.1579	.50146	19
E8	2.0000	.57735	19
F8	1.9474	.52427	19
G8	2.2632	.56195	19
H8	2.0000	.57735	19
I8	2.1053	.56713	19
J8	2.1053	.45883	19

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Seat	Pillai's Trace	.316	1.000[b]	6.000	13.000	.465	.316
	Wilks' Lambda	.684	1.000[b]	6.000	13.000	.465	.316
	Hotelling's Trace	.462	1.000[b]	6.000	13.000	.465	.316
	Roy's Largest Root	.462	1.000[b]	6.000	13.000	.465	.316

a. Design: Intercept
Within Subjects Design: Seat

b. Exact statistic

Mauchly's Test of Sphericity[a]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Seat	.000	.	44	.	.390	.496	.111

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept
Within Subjects Design: Seat

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Seat	Sphericity Assumed	1.389	9	.154	1.470	.163	.076
	Greenhouse-Geisser	1.389	3.509	.396	1.470	.227	.076
	Huynh-Feldt	1.389	4.463	.311	1.470	.214	.076
	Lower-bound	1.389	1.000	1.389	1.470	.241	.076
Error(Seat)	Sphericity Assumed	17.011	162	.105			
	Greenhouse-Geisser	17.011	63.169	.269			
	Huynh-Feldt	17.011	80.342	.212			
	Lower-bound	17.011	18.000	.945			

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Seat	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Seat	Linear	1.142E-013	1	1.142E-013	.000	1.000	.000
	Quadratic	.048	1	.048	.672	.423	.036
	Cubic	.001	1	.001	.035	.853	.002
	Order 4	.013	1	.013	.259	.617	.014
	Order 5	.015	1	.015	.107	.747	.006
	Order 6	.092	1	.092	1.474	.240	.076
	Order 7	.023	1	.023	.174	.681	.010
	Order 8	1.078	1	1.078	5.084	.037	.220
	Order 9	.118	1	.118	2.336	.144	.115
Error(Seat)	Linear	3.248	18	.180			
	Quadratic	1.293	18	.072			
	Cubic	.706	18	.039			
	Order 4	.934	18	.052			
	Order 5	2.555	18	.142			
	Order 6	1.126	18	.063			
	Order 7	2.423	18	.135			
	Order 8	3.816	18	.212			
	Order 9	.908	18	.050			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	825.347	1	825.347	491.073	.000	.965
Error	30.253	18	1.681			

Estimated Marginal Means

Seat

Estimates

Measure: MEASURE_1

Seat	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	2.105	.105	1.884	2.326
2	2.105	.105	1.884	2.326
3	2.053	.093	1.858	2.248
4	2.158	.115	1.916	2.400
5	2.000	.132	1.722	2.278
6	1.947	.120	1.695	2.200
7	2.263	.129	1.992	2.534
8	2.000	.132	1.722	2.278
9	2.105	.130	1.832	2.379
10	2.105	.105	1.884	2.326

Pairwise Comparisons

Measure: MEASURE_1

(I) Seat	(J) Seat	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.000	.000	.	.000	.000
	3	.053	.053	1.000	-.151	.257
	4	-.053	.053	1.000	-.257	.151
	5	.105	.105	1.000	-.303	.513
	6	.158	.115	1.000	-.288	.604
	7	-.158	.086	1.000	-.491	.175
	8	.105	.105	1.000	-.303	.513
	9	.000	.108	1.000	-.419	.419
	10	.000	.108	1.000	-.419	.419
2	1	.000	.000	.	.000	.000
	3	.053	.053	1.000	-.151	.257
	4	-.053	.053	1.000	-.257	.151
	5	.105	.105	1.000	-.303	.513
	6	.158	.115	1.000	-.288	.604
	7	-.158	.086	1.000	-.491	.175
	8	.105	.105	1.000	-.303	.513
	9	.000	.108	1.000	-.419	.419
	10	.000	.108	1.000	-.419	.419
3	1	-.053	.053	1.000	-.257	.151
	2	-.053	.053	1.000	-.257	.151
	4	-.105	.072	1.000	-.386	.175
	5	.053	.093	1.000	-.307	.412
	6	.105	.072	1.000	-.175	.386
	7	-.211	.096	1.000	-.583	.162
	8	.053	.093	1.000	-.307	.412
	9	-.053	.093	1.000	-.412	.307
	10	-.053	.093	1.000	-.412	.307
4	1	.053	.053	1.000	-.151	.257
	2	.053	.053	1.000	-.151	.257
	3	.105	.072	1.000	-.175	.386
	5	.158	.086	1.000	-.175	.491
	6	.211	.123	1.000	-.265	.686
	7	-.105	.105	1.000	-.513	.303
	8	.158	.115	1.000	-.288	.604
	9	.053	.093	1.000	-.307	.412
	10	.053	.120	1.000	-.413	.519
5	1	-.105	.105	1.000	-.513	.303
	2	-.105	.105	1.000	-.513	.303
	3	-.053	.093	1.000	-.412	.307
	4	-.158	.086	1.000	-.491	.175
	6	.053	.120	1.000	-.413	.519
	7	-.263	.168	1.000	-.915	.389
	8	.000	.076	1.000	-.296	.296
	9	-.105	.072	1.000	-.386	.175
	10	-.105	.105	1.000	-.513	.303

Pairwise Comparisons

Measure: MEASURE_1

(I) Seat	(J) Seat	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
6	1	-.158	.115	1.000	-.604	.288
	2	-.158	.115	1.000	-.604	.288
	3	-.105	.072	1.000	-.386	.175
	4	-.211	.123	1.000	-.686	.265
	5	-.053	.120	1.000	-.519	.413
	7	-.316	.154	1.000	-.912	.281
	8	-.053	.143	1.000	-.605	.500
	9	-.158	.138	1.000	-.693	.377
	10	-.158	.138	1.000	-.693	.377
7	1	.158	.086	1.000	-.175	.491
	2	.158	.086	1.000	-.175	.491
	3	.211	.096	1.000	-.162	.583
	4	.105	.105	1.000	-.303	.513
	5	.263	.168	1.000	-.389	.915
	6	.316	.154	1.000	-.281	.912
	8	.263	.150	1.000	-.318	.844
	9	.158	.138	1.000	-.377	.693
	10	.158	.138	1.000	-.377	.693
8	1	-.105	.105	1.000	-.513	.303
	2	-.105	.105	1.000	-.513	.303
	3	-.053	.093	1.000	-.412	.307
	4	-.158	.115	1.000	-.604	.288
	5	.000	.076	1.000	-.296	.296
	6	.053	.143	1.000	-.500	.605
	7	-.263	.150	1.000	-.844	.318
	9	-.105	.072	1.000	-.386	.175
	10	-.105	.072	1.000	-.386	.175
9	1	.000	.108	1.000	-.419	.419
	2	.000	.108	1.000	-.419	.419
	3	.053	.093	1.000	-.307	.412
	4	-.053	.093	1.000	-.412	.307
	5	.105	.072	1.000	-.175	.386
	6	.158	.138	1.000	-.377	.693
	7	-.158	.138	1.000	-.693	.377
	8	.105	.072	1.000	-.175	.386
	10	.000	.108	1.000	-.419	.419
10	1	.000	.108	1.000	-.419	.419
	2	.000	.108	1.000	-.419	.419
	3	.053	.093	1.000	-.307	.412
	4	-.053	.120	1.000	-.519	.413
	5	.105	.105	1.000	-.303	.513
	6	.158	.138	1.000	-.377	.693
	7	-.158	.138	1.000	-.693	.377
	8	.105	.072	1.000	-.175	.386
	9	.000	.108	1.000	-.419	.419

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	.316	1.000[a]	6.000	13.000	.465	.316
Wilks' lambda	.684	1.000[a]	6.000	13.000	.465	.316
Hotelling's trace	.462	1.000[a]	6.000	13.000	.465	.316
Roy's largest root	.462	1.000[a]	6.000	13.000	.465	.316

Each F tests the multivariate effect of Seat. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

```
GLM A9 B9 C9 D9 E9 F9 G9 H9 I9 J9
 /WSFACTOR=Seat 10 Polynomial
 /METHOD=SSTYPE(3)
 /EMMEANS=TABLES(Seat) COMPARE ADJ(BONFERRONI)
 /PRINT=DESCRIPTIVE ETASQ
 /CRITERIA=ALPHA(.05)
 /WSDESIGN=Seat.
```

INSTRUCTIONS FOR SEATS CONTAINING SEAT BELT RETRACTORS

1. Before beginning, ensure that all the restraints are in their proper design location and are not rotated forward or rearward of intended location.

2. Locate the 5th point belt and buckle assembly and lengthen the belt to provide working room. Attach both lap belts and both shoulder belts to the fifth point belt buckle assembly. (Figure 125)

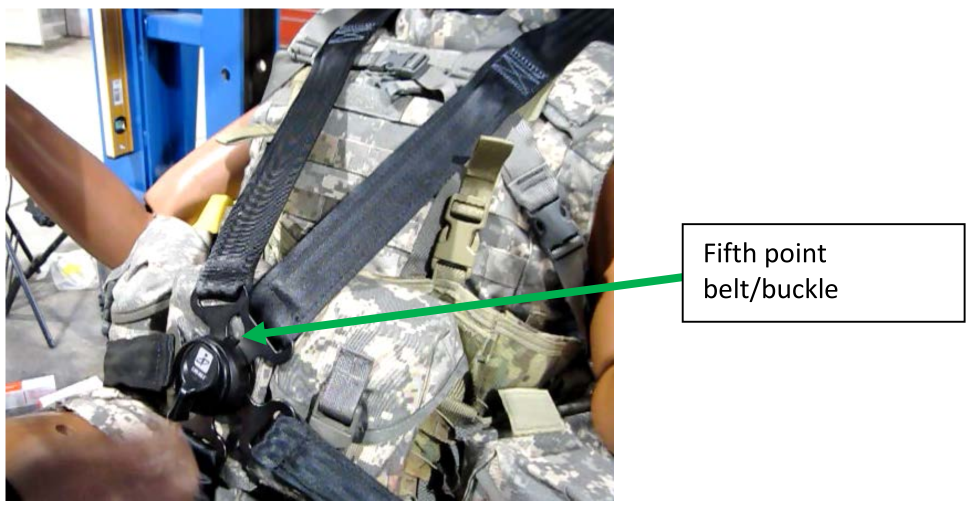

Figure 125: Fifth Point Lengthening

3. Position the buckle assembly at the pants waist. (Where pants and shirt meet, centerline of ATD.) Tighten the 5th point belt to keep buckle in position. (Figure 126)

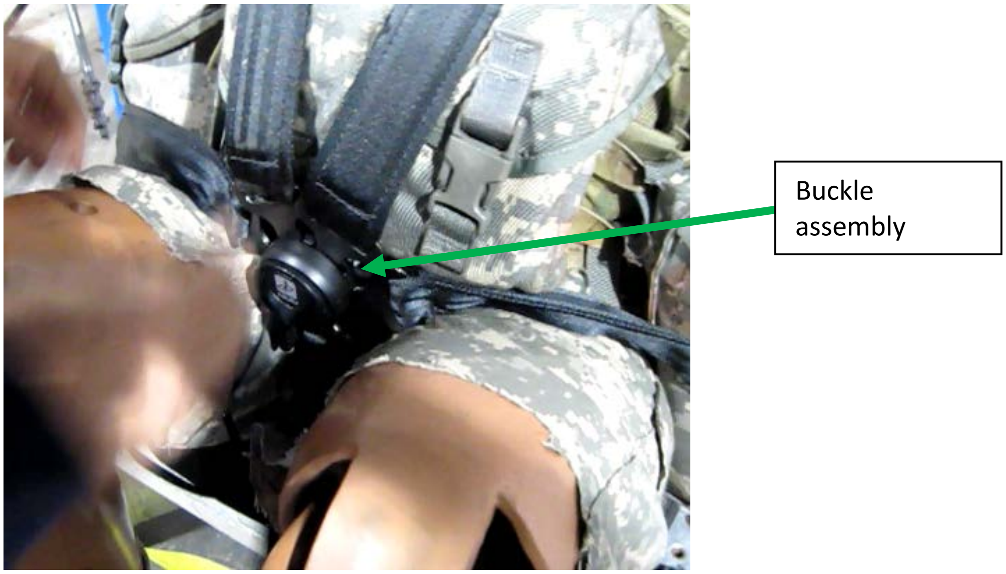

Figure 126: Buckle Centerline

Route the left and right lap belts under any pouches and insert the tongues into the buckle. The belts can be over the IOTV. (Figure 127)

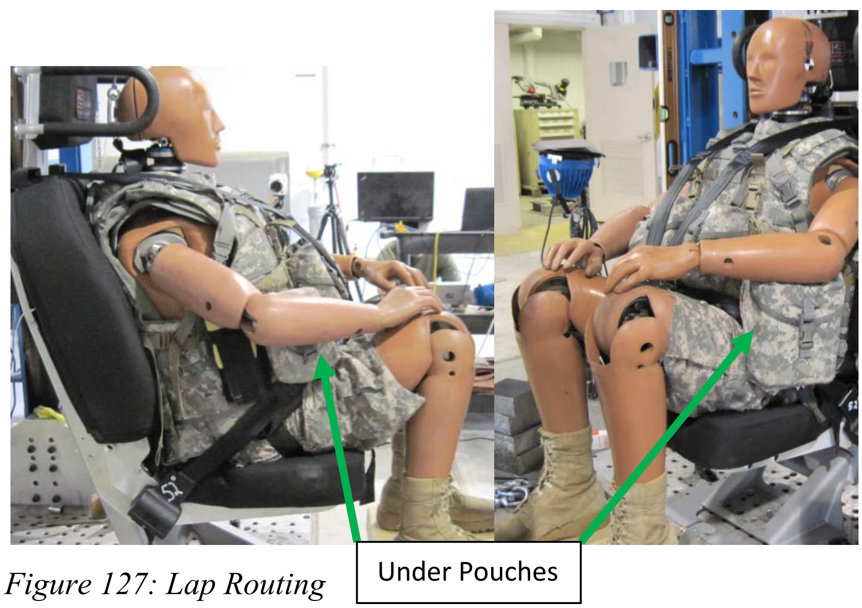

Figure 127: Lap Routing

4. Route the left and right shoulder belts over any pouches on the chest and insert

the tongues into the buckle. Make sure the belts stay close to the center of the chest. (Figure 128)

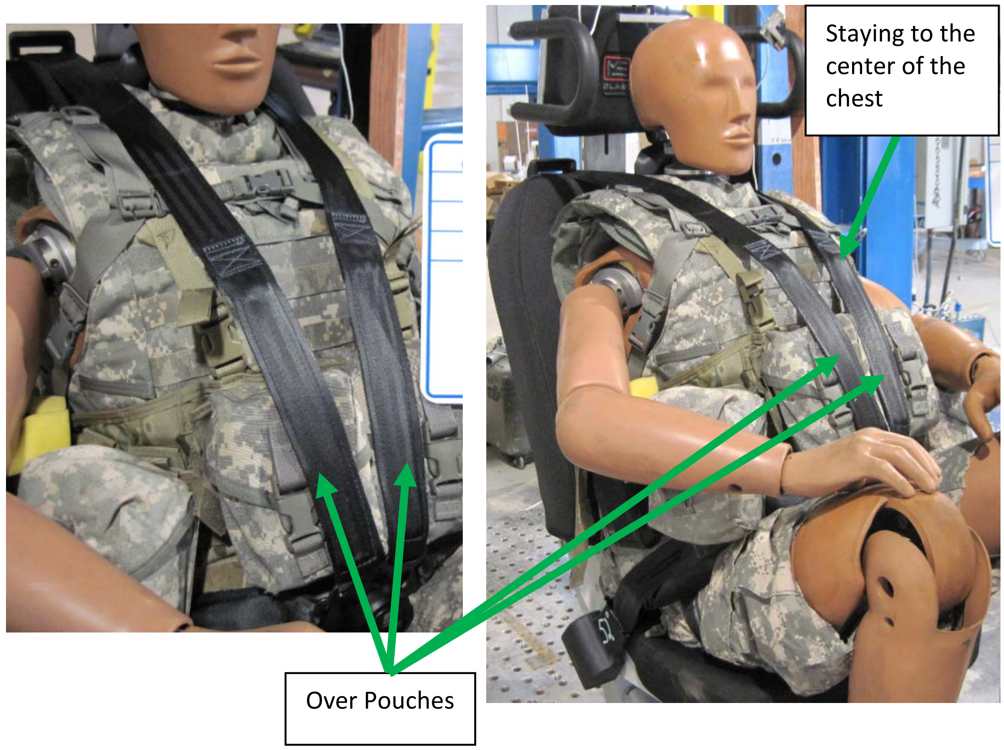

Figure 128: Shoulder Restraint Routing

5. Pull the fifth point belt tight to position the buckle assembly at the waist.

6. Cycle the lap and shoulder lap belts to ensure that they are unlocked. (Figure 129)

Figure 129: Lap Cycling

7. Confirm that the buckle assembly is still at the waist, the lap belts are under the pouches, the shoulder belts are routed over the pouches as applicable, the belts are not crossed, the belts are not twisted, and that the belts are lying as flat as possible.

INSTRUCTIONS FOR SEATS CONTAINING FIXED RESTRAINTS (ANCHORAGE POINTS)

1. Before beginning, ensure that all the restraints are in their proper design location and are not rotated forward or rearward of intended location.

2. Completely lengthen/loosen all belts.

3. Locate the 5^{th} point belt and buckle assembly and attach both lap belts and both shoulder belts into the fifth point belt buckle assembly. (Figure 130)

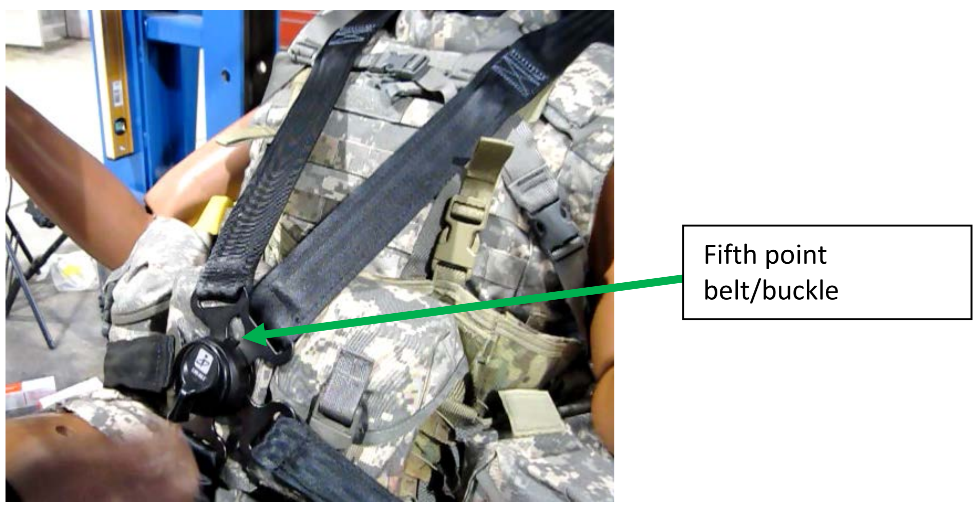

Figure 130: Manual Restraint 5th Point

4. Position the buckle assembly at the waist. (Where pants and shirt meet, centerline of ATD.) (Figure 131)

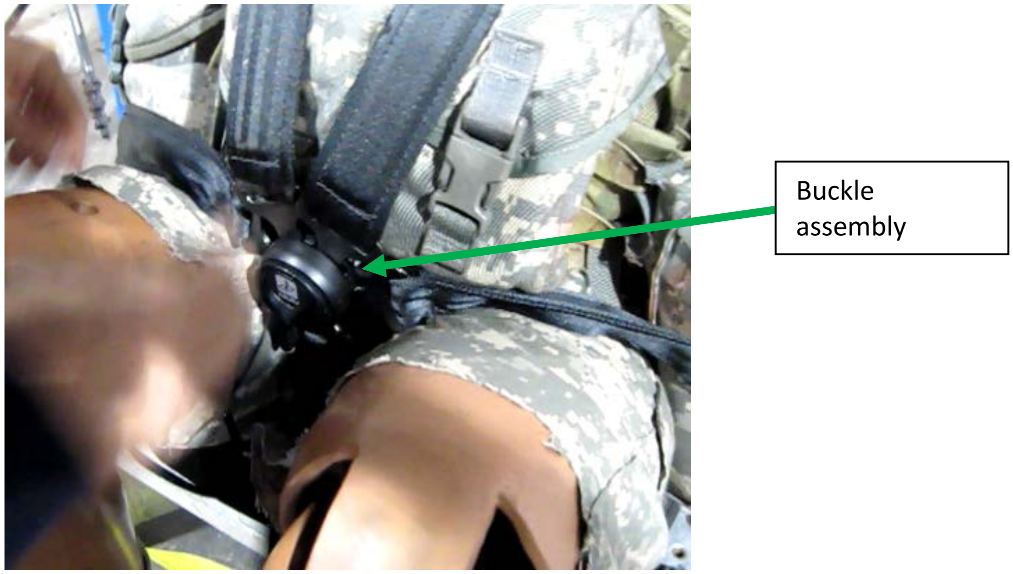

Figure 131: Buckle Centerline

5. Remove the excessive belt slack, first by pulling on the fifth point, then the left and right lap belt, and finally on the left and right shoulder belts leaving approximately 1 inch of slack in each lap and shoulder belt so there is the ability to route the belts.

6. Route the left and right lap belts under any pouches and insert the tongues into the buckle. The belts can be over the IOTV. (Figure 132) Tighten the lap belts. When the belts are tight, two fingers positioned side by side, should be able to slide under the belts at a location on the side by the IOTV.

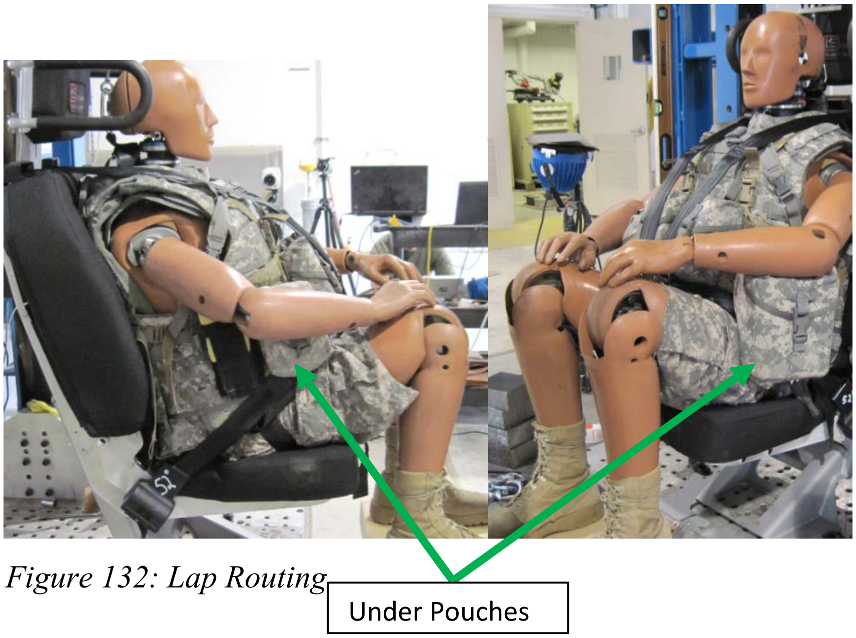

Figure 132: Lap Routing

7. Route the left and right shoulder belts over any pouches on the chest and insert the tongues into the buckle. Make sure the belts stay closer to the center of the chest. Tighten the shoulder belts. When the belts are tight, two fingers positioned side by side, should be able to slide under the belt located on the shoulder of the ATD. (Figure 133)

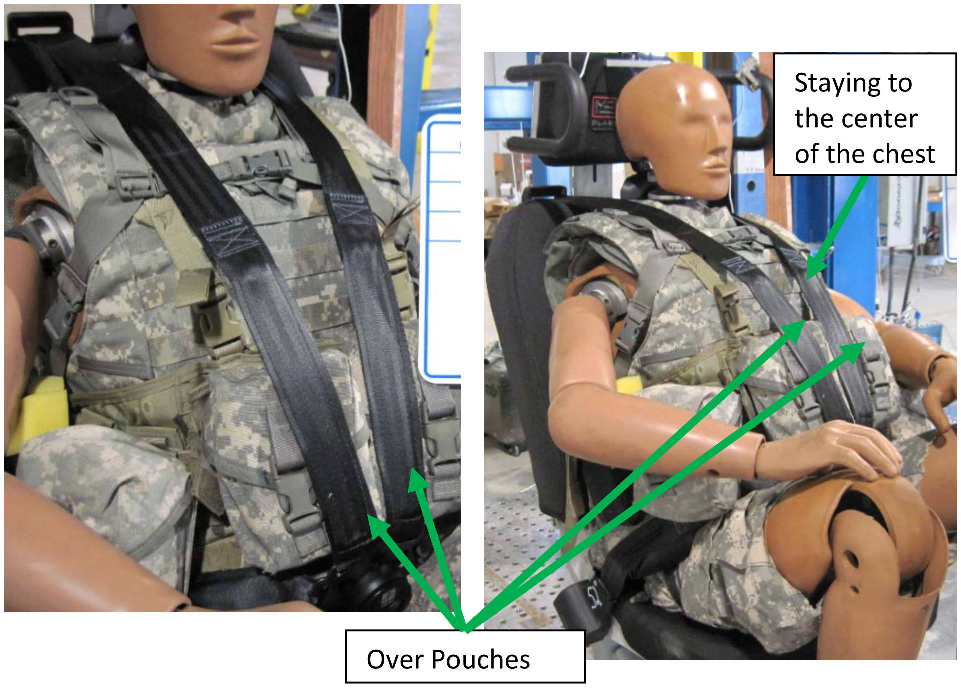

Figure 133: Shoulder Restraint Routing

8. Confirm that the buckle assembly is still at the waist, the lap belts are under the pouches, the shoulder belts are routed over the pouches as applicable, the belts are not crossed, the belts are not twisted, and that the belts are lying as flat as possible.

9. Check belt tightness again by sliding two fingers under the lap belts and shoulder belts as described in steps 5 and 6.

Appendix I: Gear Comparison Injury data

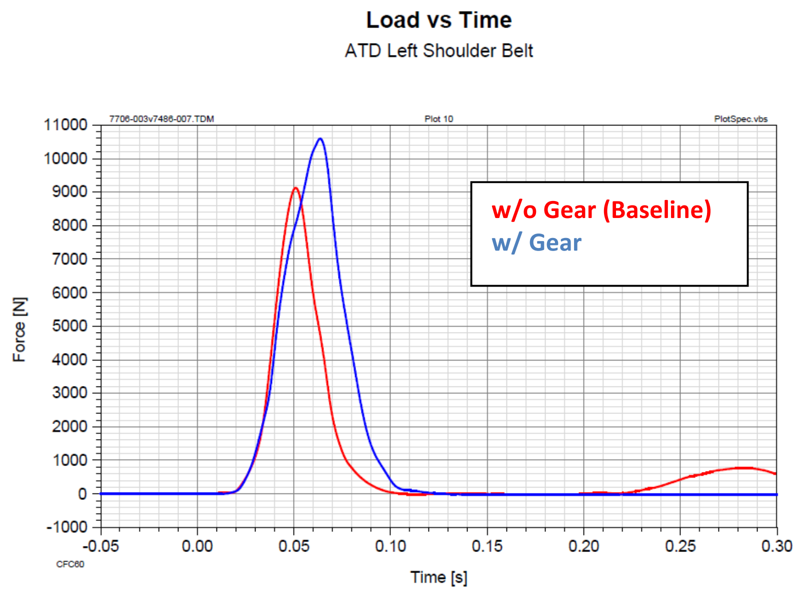

Figure 134: Left Shoulder Belt Load Cell Data

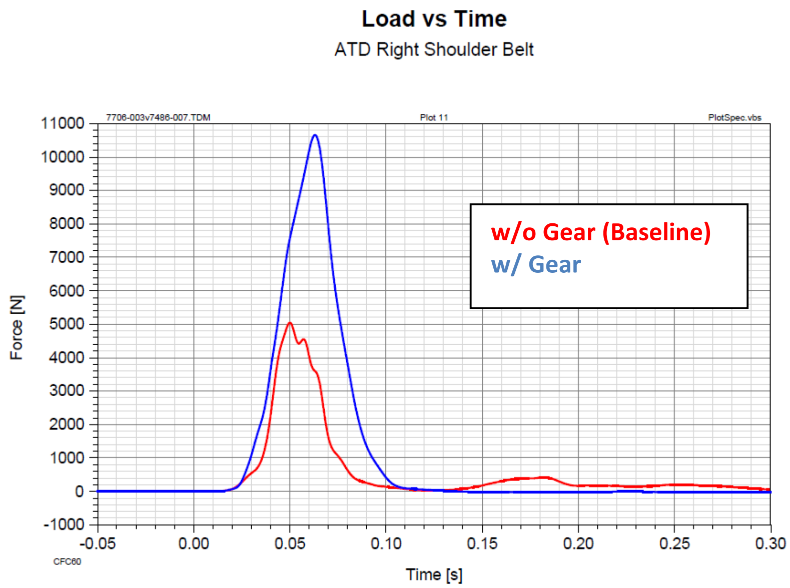

Figure 135: Right Shoulder Belt Load Cell Data

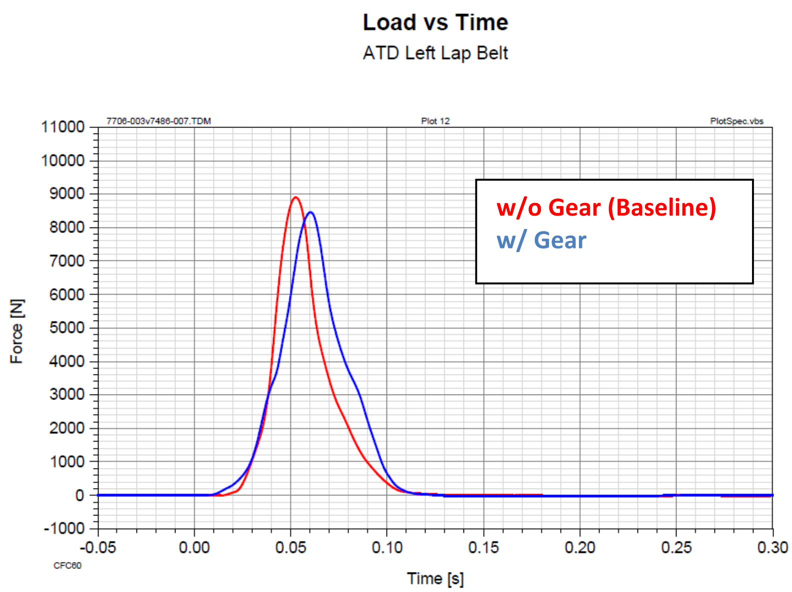

Figure 136: Left Lap Belt Load Cell Data

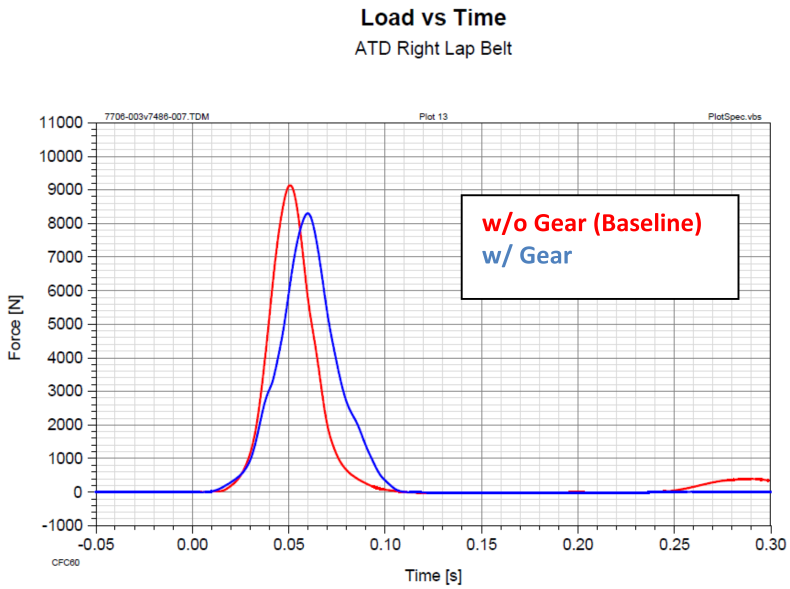

Figure 137: Right Lap Belt Load Cell Data

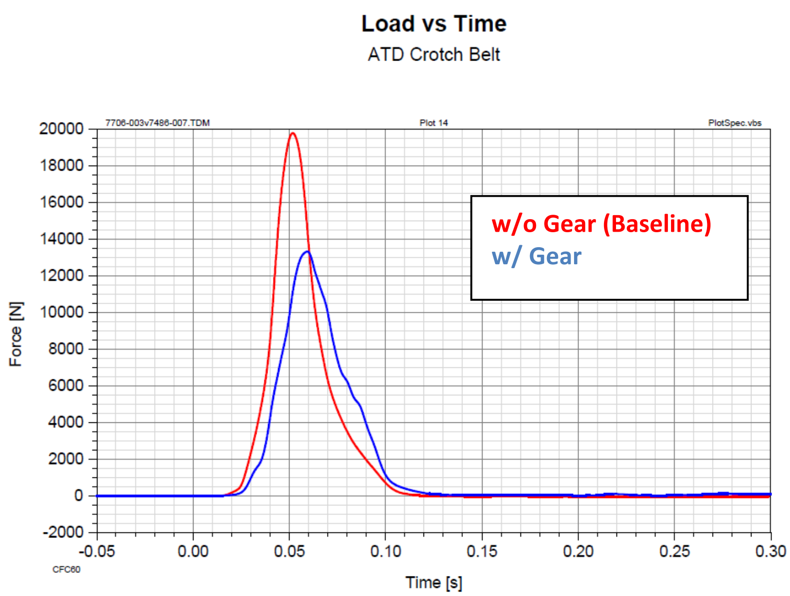

Figure 138: 5th Point Belt Load Cell Data

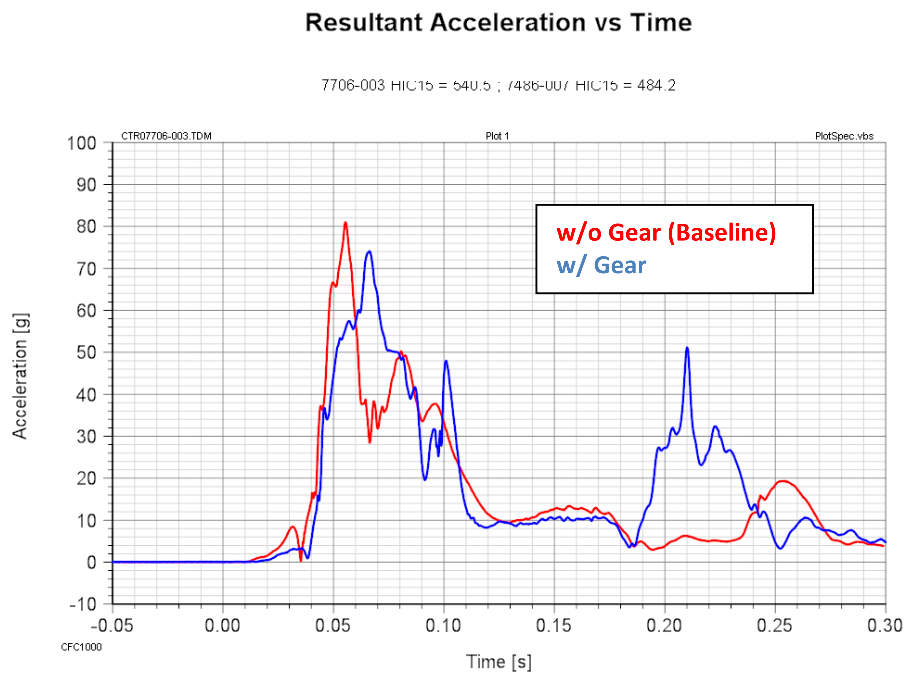

Figure 139: Head Resultant

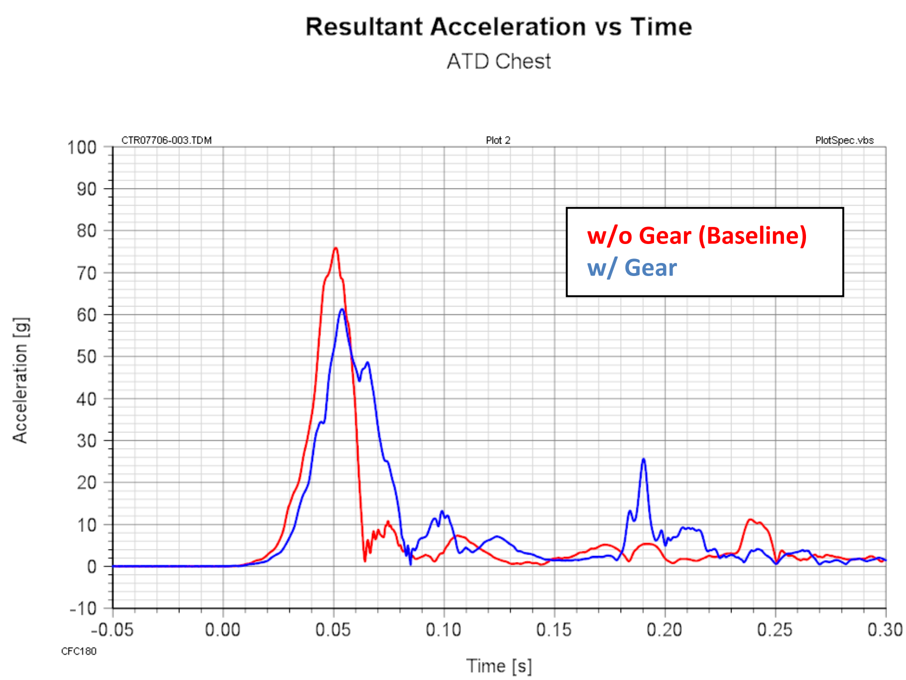

Figure 140: Chest Resultant

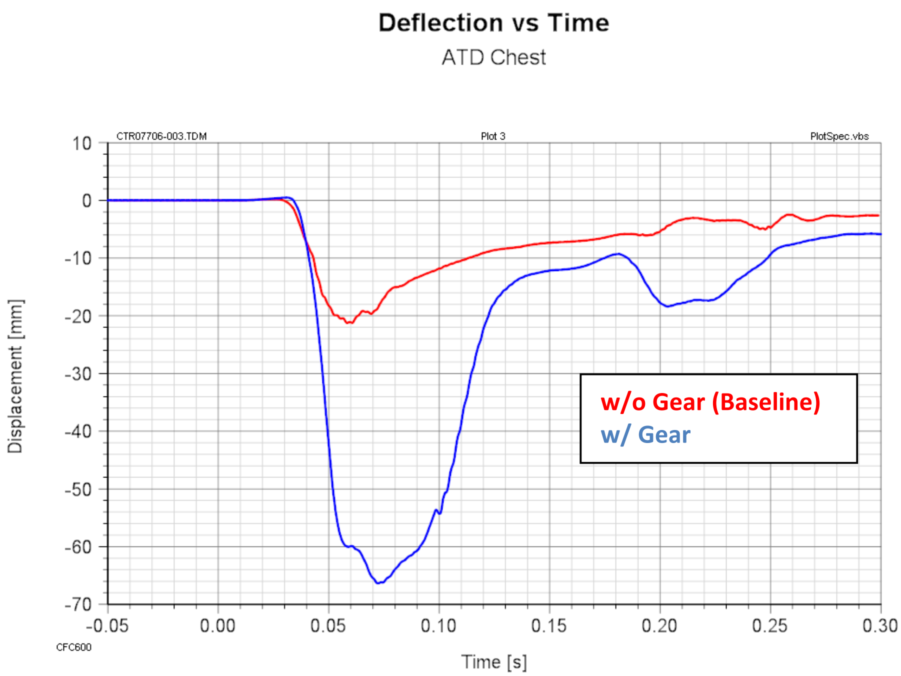

Figure 141: Chest Deflection

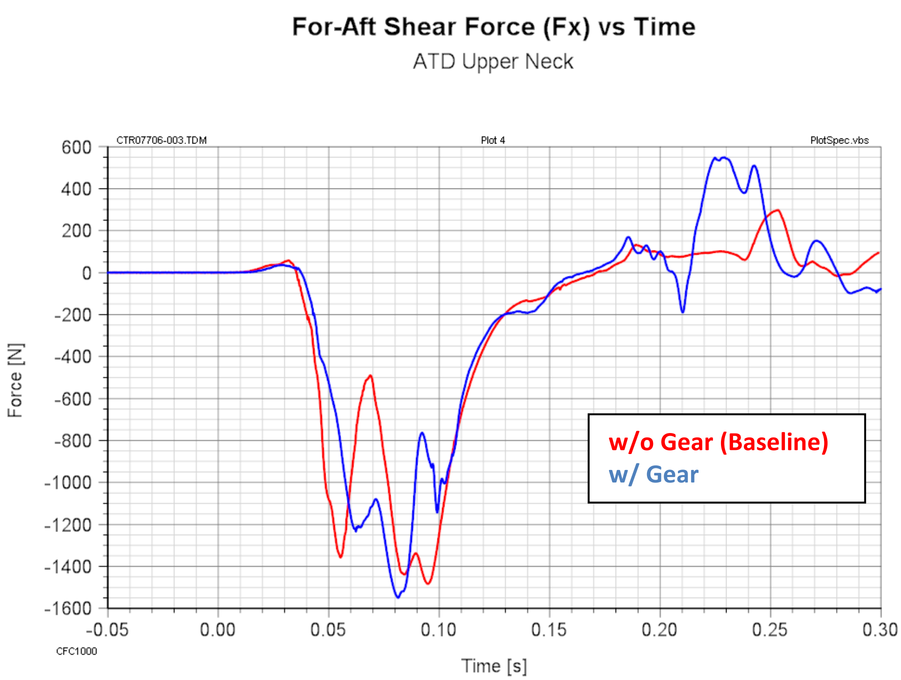

Figure 142: Neck FX

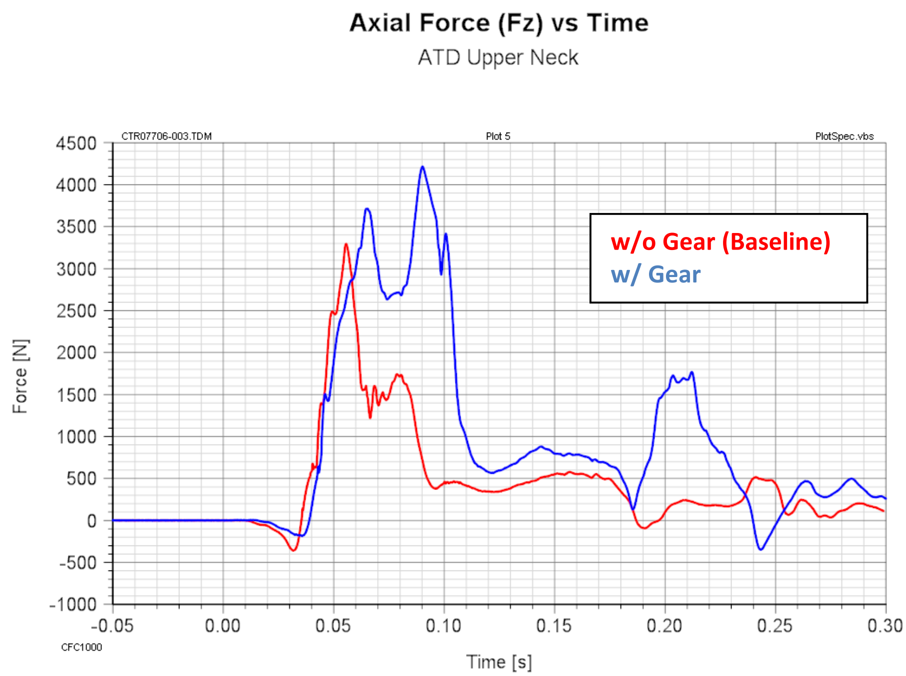

Figure 143: Neck Fz

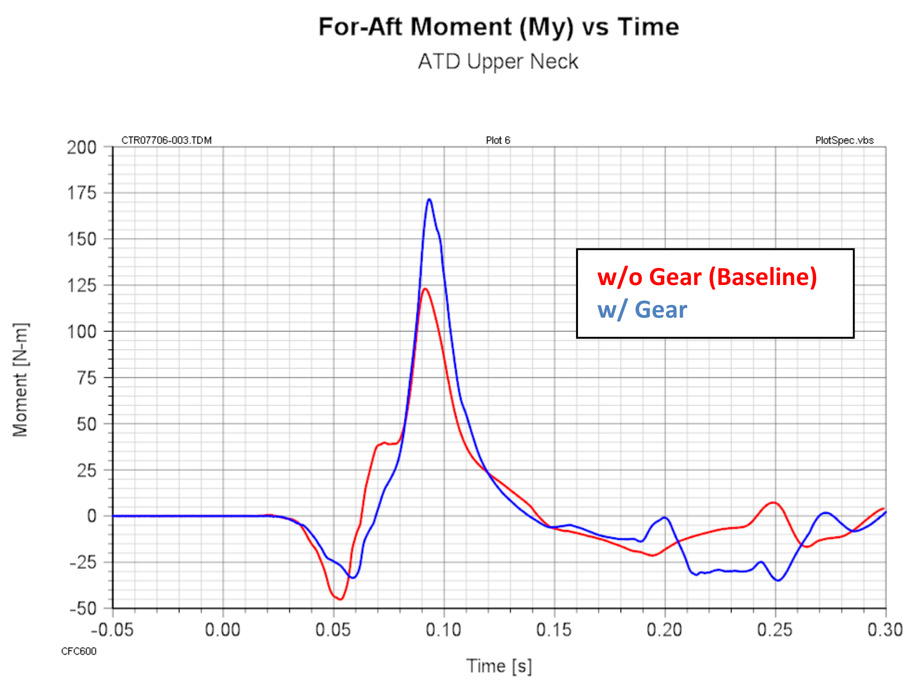

Figure 144: Neck My

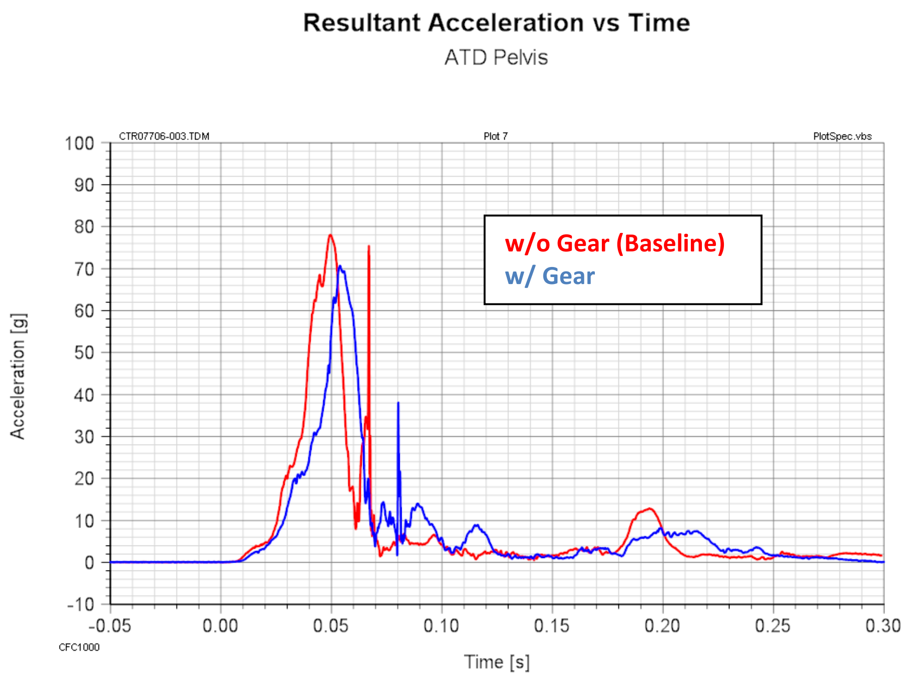

Figure 145: Pelvis Resultant

Appendix J: PULSE Comparison Injury data

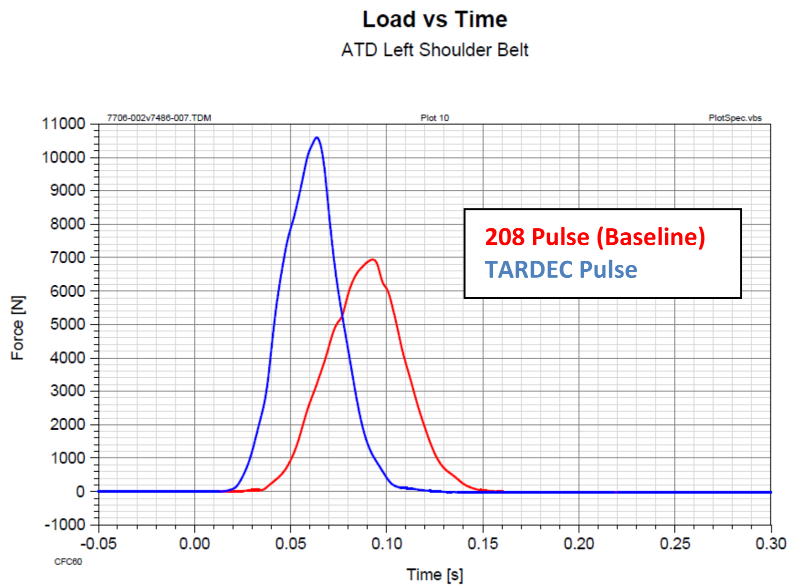

Figure 146: Left Shoulder Belt Load Cell Data

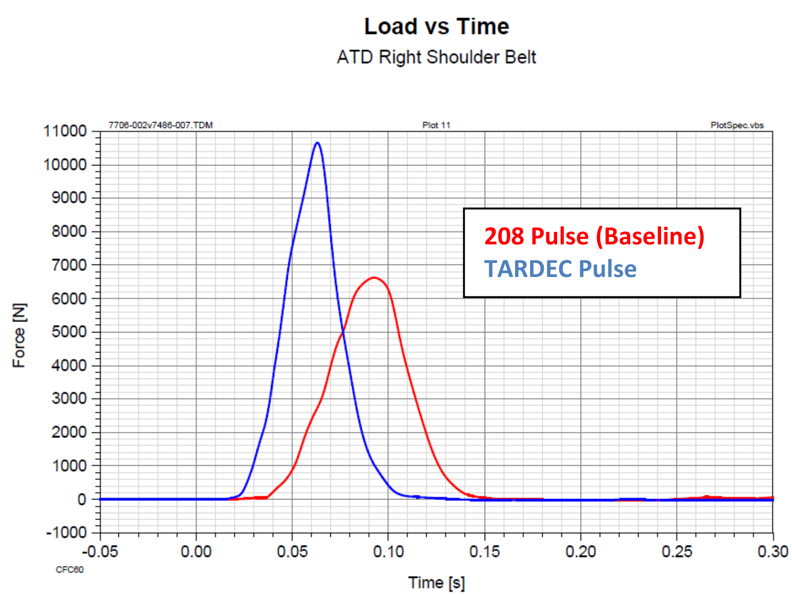

Figure 147: Right Shoulder Belt Load Cell Data

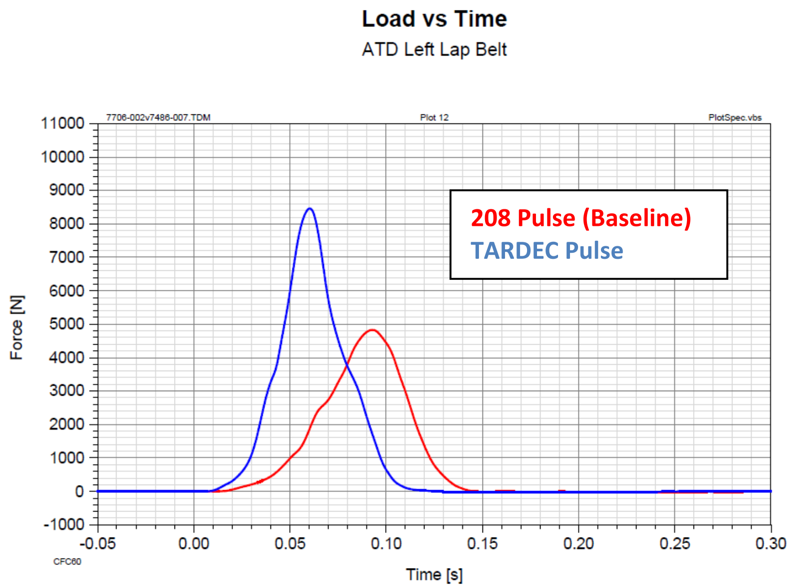

Figure 148: Left Lap Belt Load Cell Data

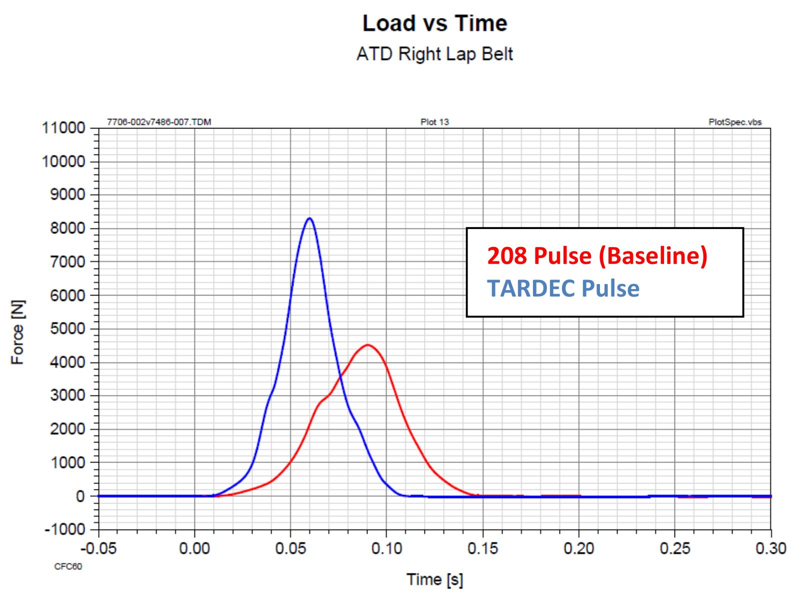

Figure 149: Right Lap Belt Load Cell Data

Load vs Time

ATD Crotch Belt

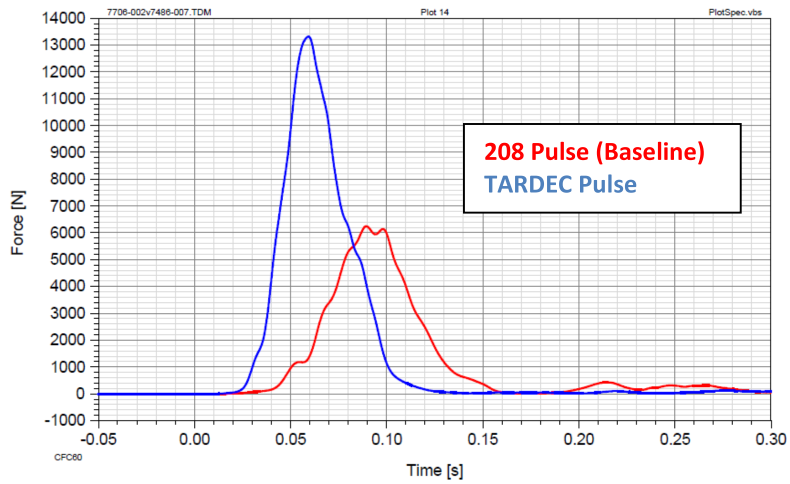

Figure 150: 5th Point Belt Load Cell Data

Resultant Acceleration vs Time

7706-002 HIC15 = 187.8 ; 7486-007 HIC15 = 484.2

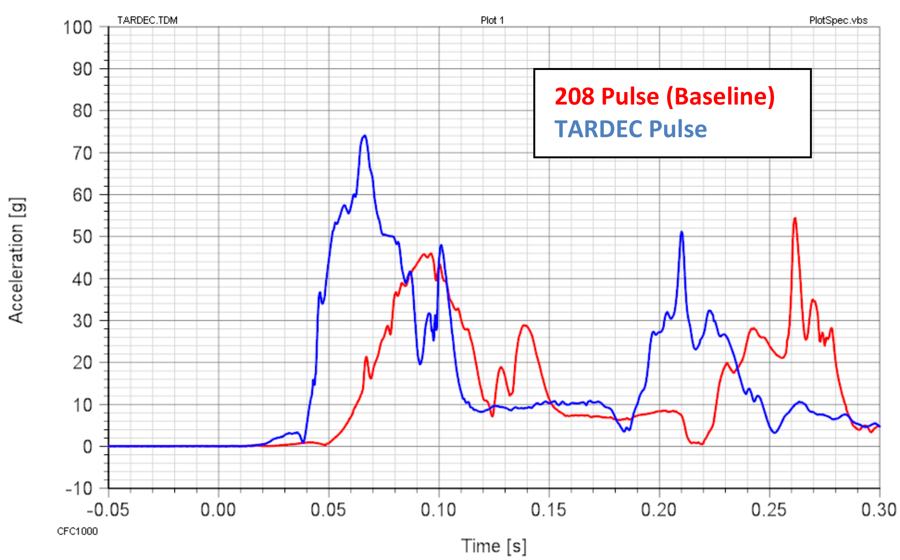

Figure 151: Head Resultant

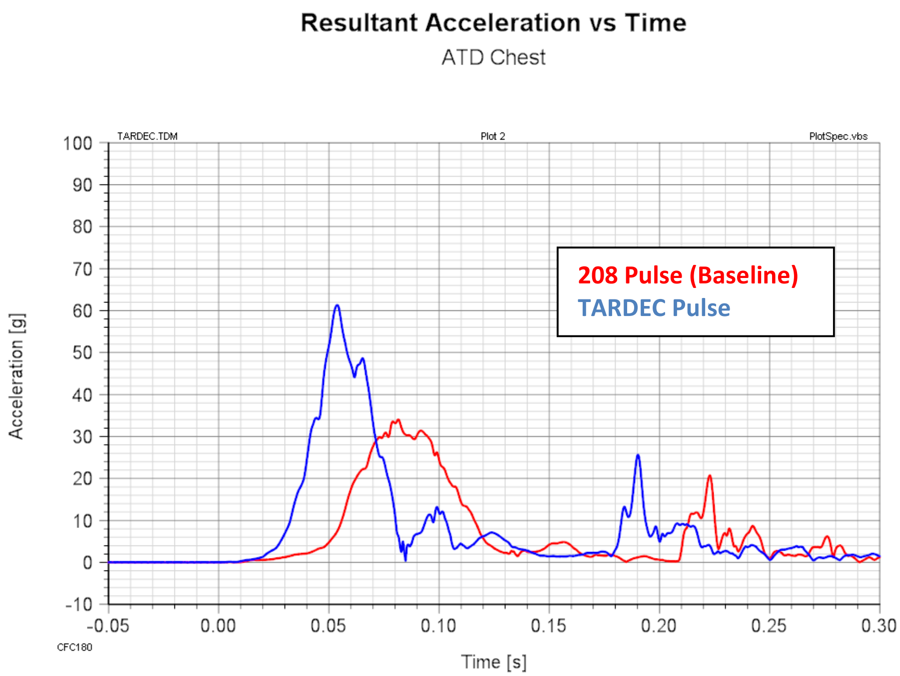

Figure 152: Chest Resultant

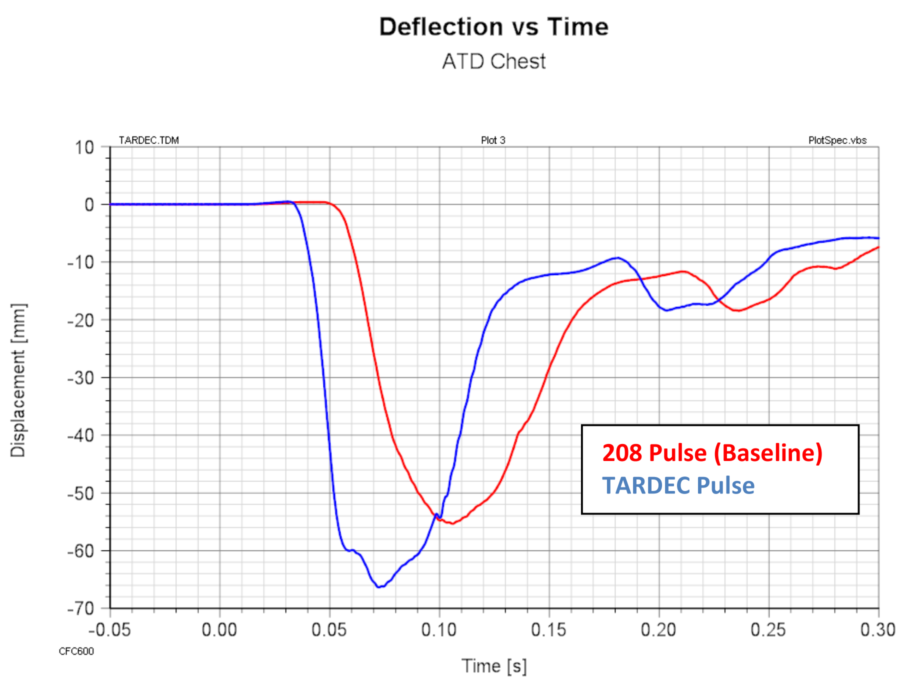

Figure 153: Chest Deflection

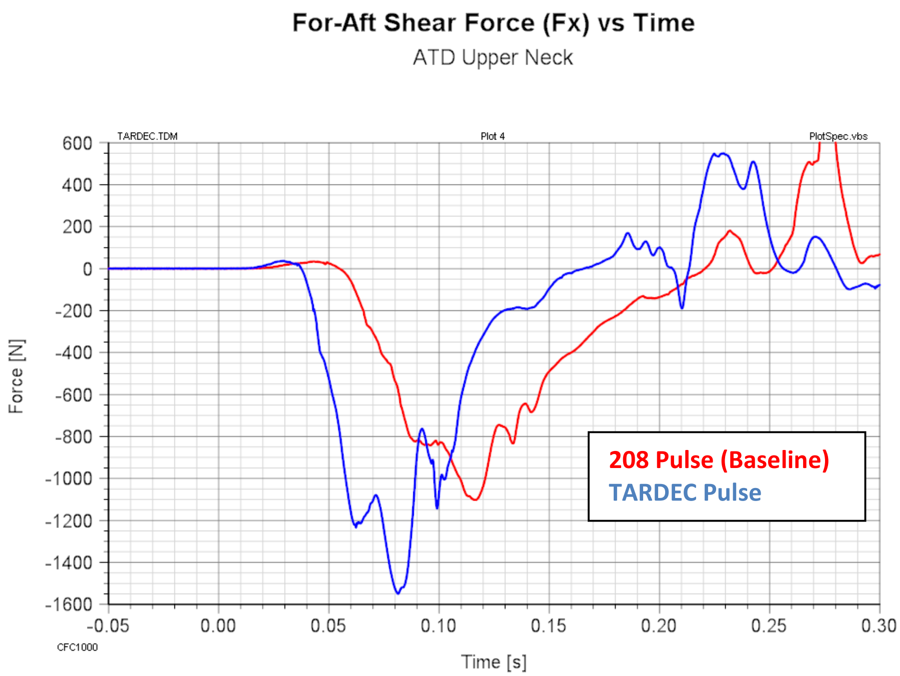

Figure 154: Neck FX

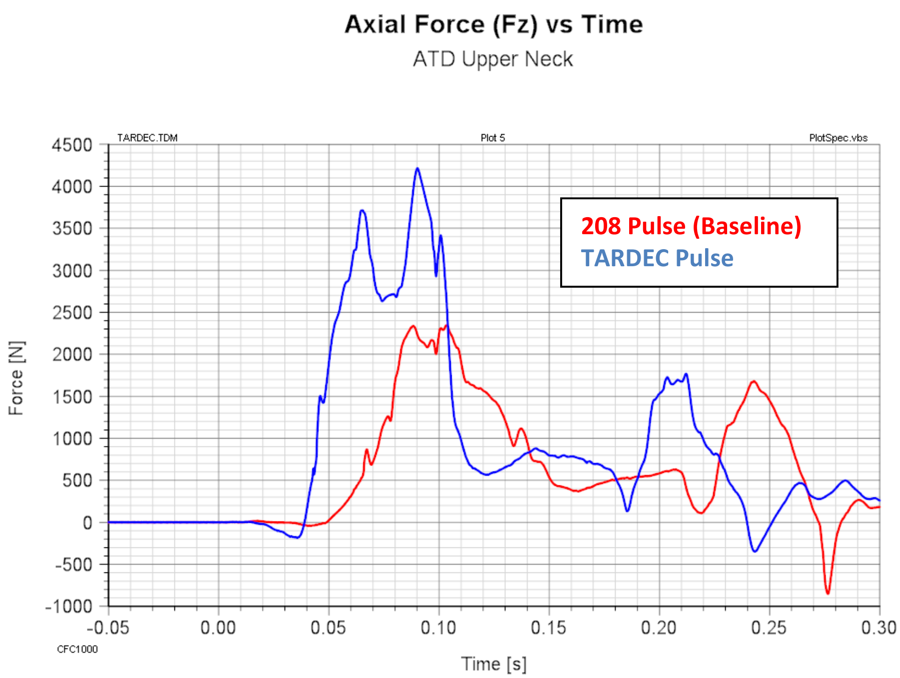

Figure 155: Neck Fz

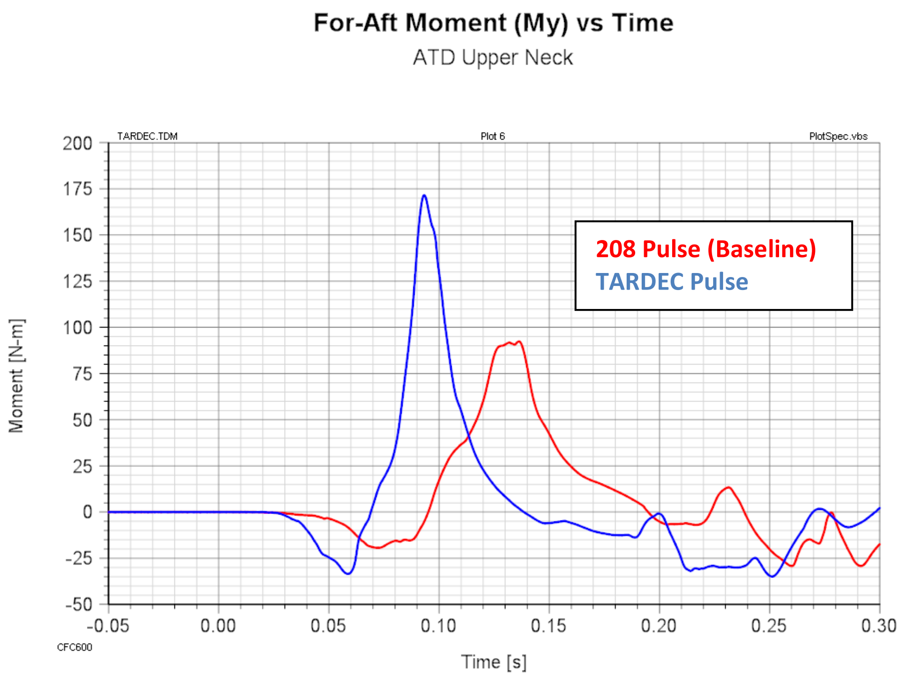

Figure 156: Neck My

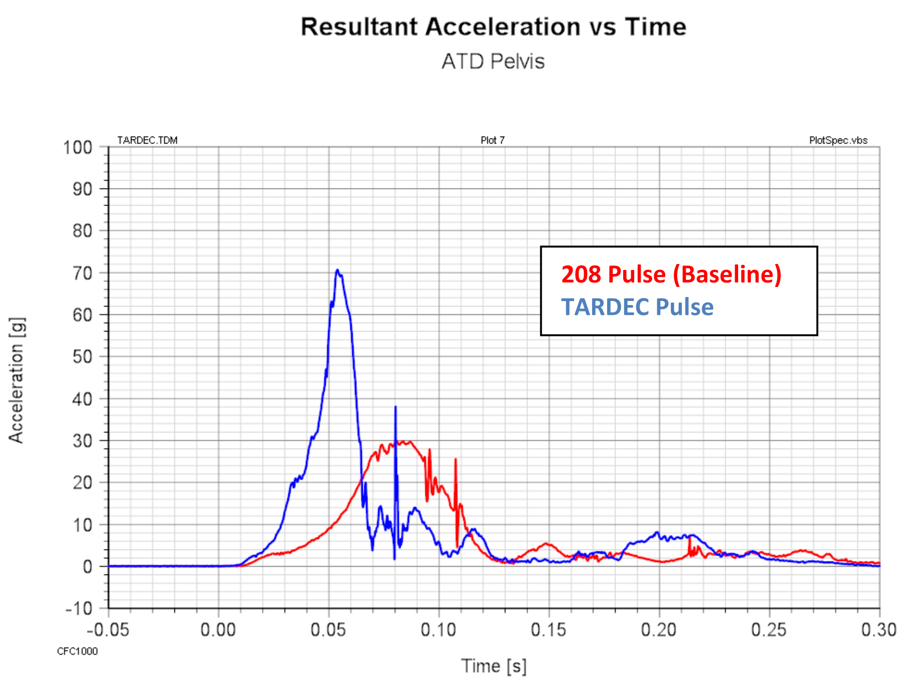

Figure 157: Pelvis Resultant

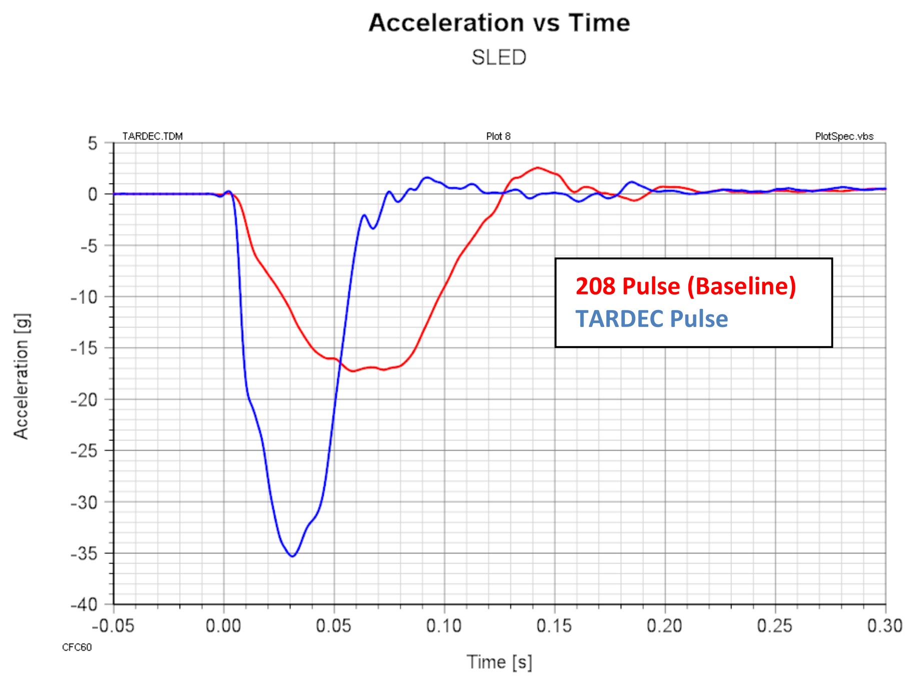

Figure 158: Pulse Acceleration Comparison